FLOATING TYBEE:

PLANNING AND DESIGNING FOR RISING SEAS

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FLOATING TYBEE:

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SUMMARY

There is a statistically high probability that within this generation's lifetime the mean sea level in the southeastern coast of the United States will rise from three to six feet above what it is today. Two major contributing factors to this sea level rise are the melting of ice sheets and thermal expansion of the planet's oceans. These factors are results of a warming global climate which is a trend not easily reversed. Regional rises in sea levels are going to be a persistent problem in the coming century.

Much planning and designing for challenges presented by sea level rise are beginning to emerge. Any plan relating to sea level rise falls into one of three categories (or some hybrid): Retreat, Defend, or Adapt. Most plans influenced by citizen and community input, in an attempt to mitigate damage to personal property fall into the "defend" category. Plans that focus on environmental preservation and ecological awareness follow the strategy of "retreat". The strategy of adapt, which is often neglected, must be focused upon because it contains many positive and few negative aspects of both "defend" and "retreat".

Using an adaptive strategy, this thesis asks the question "How can sea level rise be converted from a liability into an asset?" Using Tybee Island of Chatham County Georgia as a case study, it is clear that the strategy used cannot be one of defense or retreat. A strategy of pure defense would destroy the ecological and economic viability of the island. A strategy of pure retreat would leave the island abandoned and would cripple the economy of coastal Georgia. A strategy is needed that will enable habitation of the island without destroying the island itself. Sea level rise must be viewed as a force of nature that will facilitate planning action and help to form a new cultural and economic identity for Tybee Island, not a force of nature that must be combatted or fled from.

This thesis will communicate how sea level rise can be incorporated into a plan for the island in four chapters. The first chapter explains the current knowledge and projections of sea level rise. The second chapter describes the barrier islands of coastal Georgia and Tybee Island. The third chapter describes and critiques the current adaptation plan for Tybee Island. The fourth chapter describes a new plan and urban design strategy for Tybee Island. The fifth chapter introduces existing instances of aquatic architecture from around the world, and proposes a new type of amphibious architecture specific to Tybee Island.

The new adaptive plan for Tybee bridges many disciplines including planning policy, urban design, architecture, real estate, and economics. This thesis posits that we can protect human property and natural ecology simultaneously will take time, effort, foresight, and planning, but this thesis lies out the framework to adapting Tybee Island to a coming rise in sea levels.

CHAPTER 1: *OCEAN ON THE RISE*

SEA LEVEL RISE (causes) –

The climate of planet earth is warming with each passing year and a consequence of this climate change is a rise in global sea levels. Data and scientific reports show that the level of greenhouse gases in our atmosphere has been climbing which results in the raising of global temperatures. Greenhouse gases such as methane, water vapor, and carbon dioxide (among others) prevent solar radiation, when reflected off of the planet, from escaping our atmosphere. This retention of solar radiation leads to the transmission of its energy into our atmosphere, whether this transmission is sensible or latent.[1]

Figure 1.1 shows data recovered by Charles Keeling regarding the increasing presence of carbon dioxide in our atmosphere. It shows an increase of CO2 in our atmosphere from roughly 330 ppm (parts per million) in 1975 to ~380ppm in 2007. This data acquired at the Mauna Loa Observatory in Hawaii is irrefutable. This report is one of many which confirm that $C0_2$ levels, along with other GHG levels, are increasing and as a result the atmosphere is heating up. A major side effect of global warming is for sea levels to rise. When simply put: ice melts and objects expand when heated. Remote sensing and GIS analyses have linked the melting of the ice sheets on Antarctica and Greenland and the thermal expansion of the oceans with elevating sea

[1] Stone, Brian. *The City and the Coming Climate: Climate Change in the Places We Live*

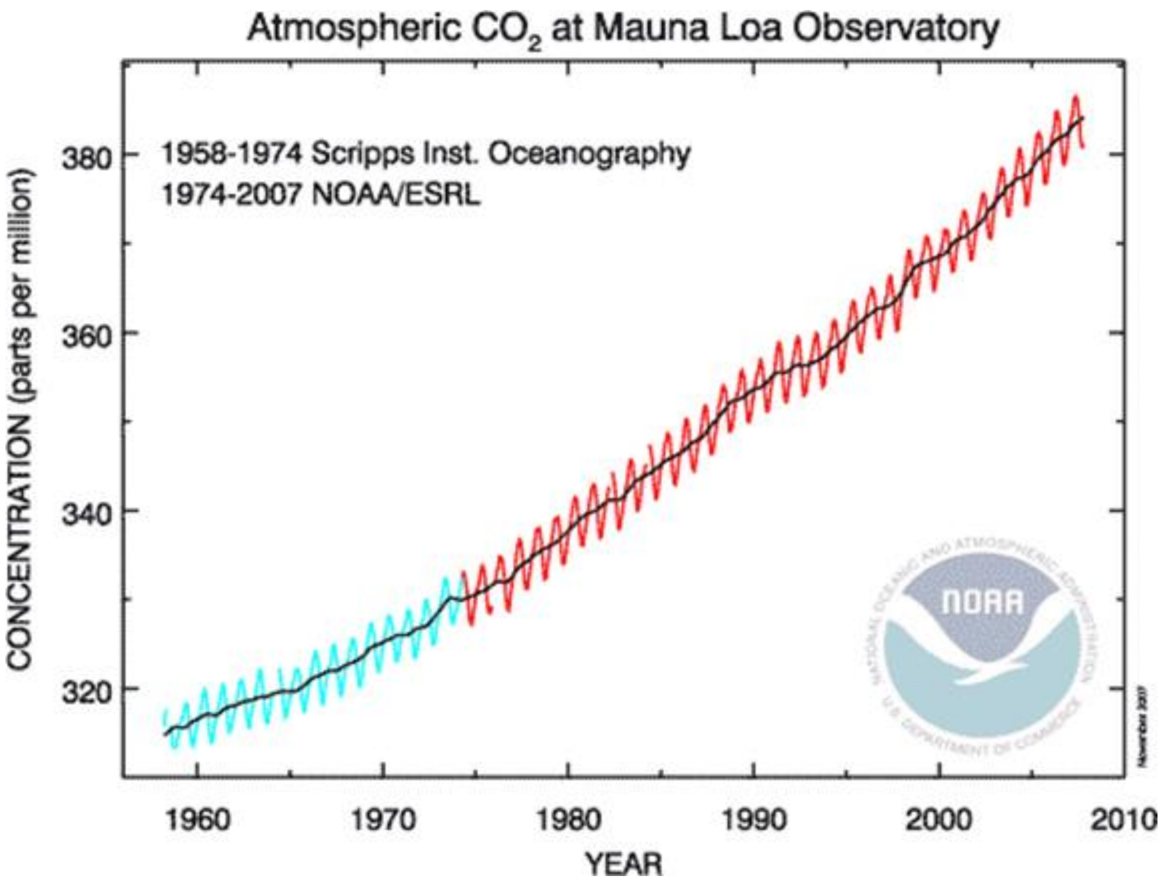

Figure 1.1 (Mauna Loa CO2 Data)

levels. Thus, sea level rise can be mainly attributed to global warming because both the melting of the ice sheets and the expansion of ocean water are direct results of elevated temperatures.

SEA LEVEL RISE (projections) –

It should be noted that though the reports and projections use units of time to describe the occurrence of sea level rise, time should be considered elastic for the purposes of planning and designing for sea level rise. Several organizations, governmental bodies, scientists, and journals produce reports on sea level rise, climate change, and projections for the future. Two of the most widely accepted bodies (within the scientific community) for studies and data are the IPCC and NOAA.

The IPCC, also known as the Intergovernmental Panel on Climate Change, is a panel composed of constituents of several governments and countries around the world. The IPCC was formed in 1988 by the United Nations and is the global body that establishes framework for studies being conducted around the globe. The IPCC assembles reviews, comes to a consensus on findings, and publishes data and findings. They do not conduct any studies themselves.[2] The NOAA, also known as National Oceanic and Atmospheric Administration, is a branch of the United States Department of Commerce. The NOAA is an administration strictly related to the United States and deals with a variety of topics ranging from coastal phenomenon to storm tracking in the Midwest. The NOAA conducts their own studies, research, and data collection.[3] Both of these organizations produce findings on Global Mean Sea Level Rise (GMSL), and the NOAA has more site specific (for the United States) data and research on Regional Sea Level Rise.

NOAA derives much of their climate change projections and analysis from IPCC reports, in addition to creating their own data specific to the United States. The data accumulated and synthesized by the IPCC is obtained from unpaid scientists from around the world volunteer their findings for the betterment of our planet.[4] All the data, studies, and findings volunteered are synthesized into a report by the IPCC. There have been five reports so far. The IPCC has produced reports which find that the sea level

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[2] IPCC - Intergovernmental Panel on Climate Change." *IPCC - Intergovernmental Panel on Climate Change*

[3] About NOAA." *NOAA*. National Oceanic and Atmospheric Administration

[4] "IPCC - Intergovernmental Panel on Climate Change." *IPCC - Intergovernmental Panel on Climate Change*

has been rising the past few centuries.[5] *Figure 1.2* summarizes this report on historical trends of SLR.

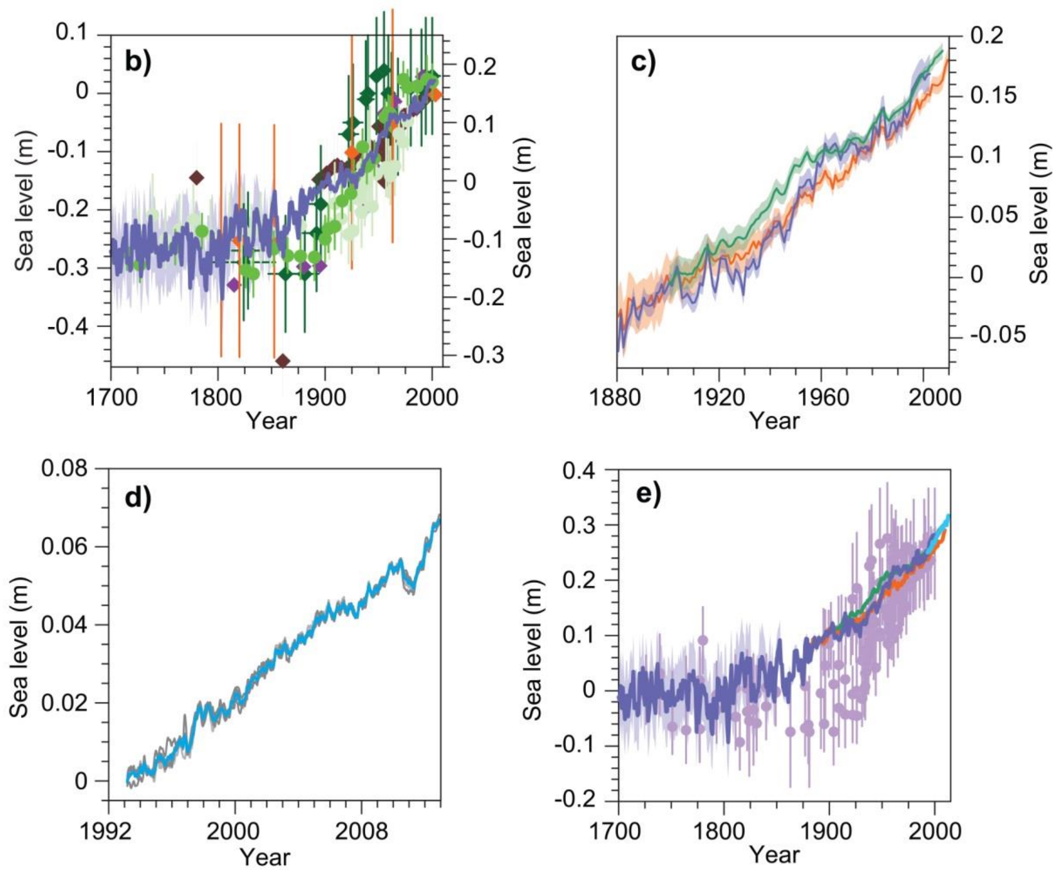

Figure 1.2 (graphs from IPCC AR5 showing historical SLR trends)

Sea level rise is not a recent phenomenon, but reports emerging from the IPCC do present conclusive evidence that this phenomenon is accelerating. The IPCC's fifth and most recent assessment report was released in September 2013, and included the following projections shown in *Figure 1.3* to be the best synthesized representation of the findings from around the world. These projections are modeled assuming future conditions of the habitation of our planet. Several "Representative Concentration Pathways" are modeled in these projections. A representative concentration pathway

[5] Church, John A., and Peter U. Clark. *IPCC: Assessment Report 5*.

(RCP) is a way to measure “Radiative Forcing” which is essentially a “measure of human emissions of (greenhouse gases) from all sources” and is measured in Watts per meter squared. The RCP shows what our emissions will look like based on projected technological, socio-economic, political, and cultural trends in the future. Some RCPs may project a future shift towards improving technology disregarding levels of emissions, while another RCP may be business as usual, and one may project a future where reduction of emissions and reversal of anthropogenic changes is a priority for society.

The highest scenario using RCP8.5 has a mean of +0.63 meters SLR with the outliers range being ±0.185. The low scenario is using RCP2.6 with a mean of +0.40 meters SLR with the outlier range being ±0.145. Both of these projections are predicted to occur sometime between 2081 and 2100. According to the fifth Assessment Report by the IPCC, the high projection for sea level rise by 2081 is +2.7 feet (0.82 meters) and the low projection for sea level rise by 2081 is +0.85 feet (.26 meters). These reports take into account a variety of contributing variables such as thermal expansion, glacial melting, ice sheet melting, rapid action on these ice sheets (Greenland and Antarctic),

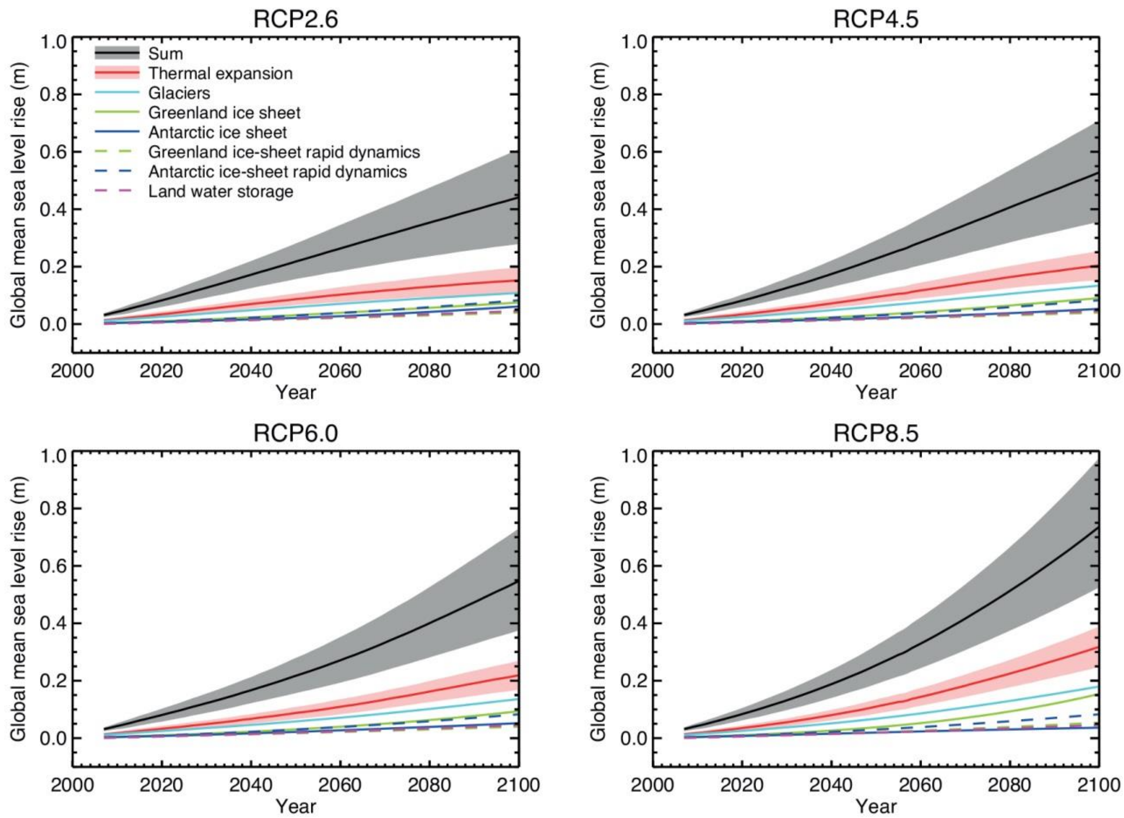

Figure 1.3 (IPCC AR5 SLR projections separated by RCP scenario)

and land water storage[6]. Any unforeseen change in these contributing variables could greatly alter the projections. For instance, if the acceleration of the melting of the Antarctic Ice Sheets was underestimated, or the repercussions of larger scale melting are not taken into account, then the future sea level rise could be much higher than currently projected. Another problem may be that these variables are not additive in nature but are more relational and interconnected, meaning that an effect on one may greatly alter the others.

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[6] Church, John A., and Peter U. Clark. *IPCC: Assessment Report 5*.

These are not simple SLR projections attained from a single data source, yet a sum of projections from a variety of scientists and a variety of variables, all of which work together to affect SLR. Some agencies, such as NOAA, attribute differing levels/significances to other variables. NOAA published a report on global sea level rise scenarios in December of 2012. Included in this report are several studies on regional sea level rise as well. The NOAA asserts that "We have a very high confidence (>9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100." (NOAA report, page 1) In *Figure 1.4* below, the intermediate-low and high projections are based on the IPPC's AR4 (assessment report 4) which is not the most current. The low projection is based on a linear extrapolation of historical sea level rise data from tide gauges dating back to 1900. The intermediate-high projection is based on averaging semi-empirical global SLR data that is on the high end.[7]

The NOAA report is in conflict with the IPCC projections, due to the previously mentioned variables and how they are interpreted. The IPCC attributes the majority of sea level rise to thermal expansion in each projection they put out.[8] The NOAA, due to recent data and research using remote sensing believes that "ice sheet loss…(is)…a greater contribution to global SLR than thermal expansion over the period of 1993 to 2008." (NOAA report, page 2). The emphasis on ice sheet loss as the main contributing variable rather than thermal expansion produces more dire projections.

[7] Parris, Adam. *Global Sea Level Rise Scenarios for the United States National Climate Assessment*.
[8] Church, John A., and Peter U. Clark. *IPCC: Assessment Report 5*.

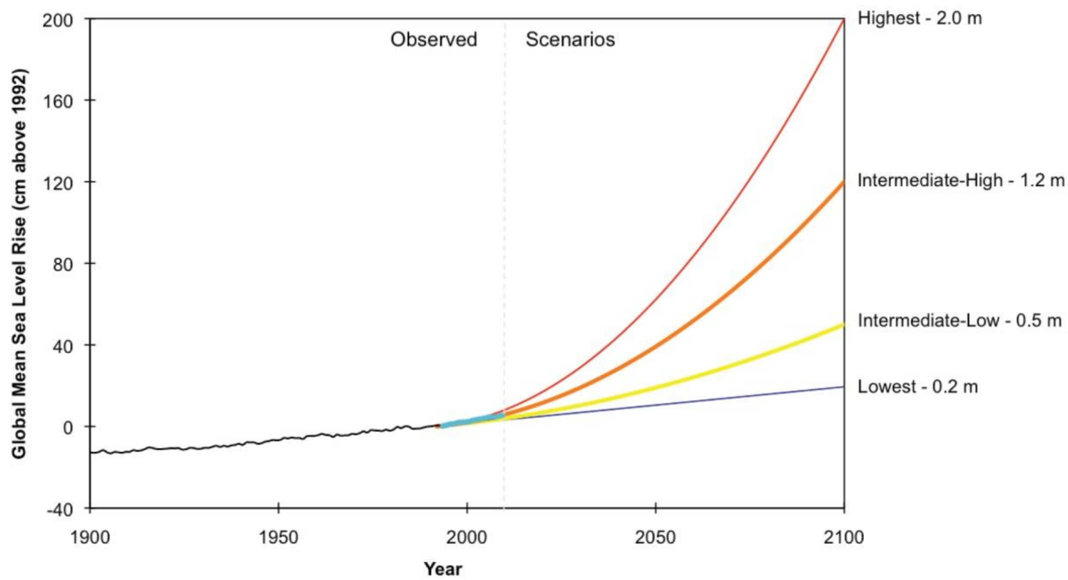

Figure 1.4 (NOAA SLR projections by 2100)

The basic comparison of these two reports demonstrates the inefficiency and confusion when linking sea level rise to periods of time. Using time as a determining variable is appropriate for illustrative purposes, yet when drawing plans in which certainty is a necessity, the uncertain time period in which SLR is to occur becomes a problem. Therefore, time is to be considered elastic when planning for SLR, and physically measured occurrences of SLR should be the new determining variable for phasing.

ASSOCIATED THREATS –

SLR is a result of a warming planet, as is extreme weather patterns such as longer periods of drought, lengthy periods of inundating precipitation, record highs in temperature, record lows in temperature, acid rain, increase severity of storms, etc.

Many of these symptoms are interrelated and connected, and they all have consequences themselves.[9] Two main threats associated with a rising regional and global sea level are higher storm surges and increased intensity of coastal storm fronts.[10] Storm surge is one of the more tangible problems resultant of higher sea levels. A sea level rise of one foot may not affect properties through typical tidal inundation, though this rise will render certain properties, which were at one point safe, now susceptible to hydrostatic and hydrodynamic forces during storms. A hydrostatic force is caused by storm surges, standing water, or water moving in a current. Hydrodynamic forces are caused by wave action.[11] Storm surge occurs when there is an elevated (above normal) status in the sea level due to the presence of a storm. This temporal rise in sea level creates a “surge” which flows from the sea onto the land causing property and ecological damage, as diagrammed in Figure 1.5.

Due to a rise in sea levels, a higher susceptibility to storm surge will become a more common occurrence for coastal towns and cities in the southeast. The exploitation of this susceptibility will become a more frequent occurrence as well. Hurricanes and tropical storms are already a devastating force of nature for coastal Georgia and Florida.

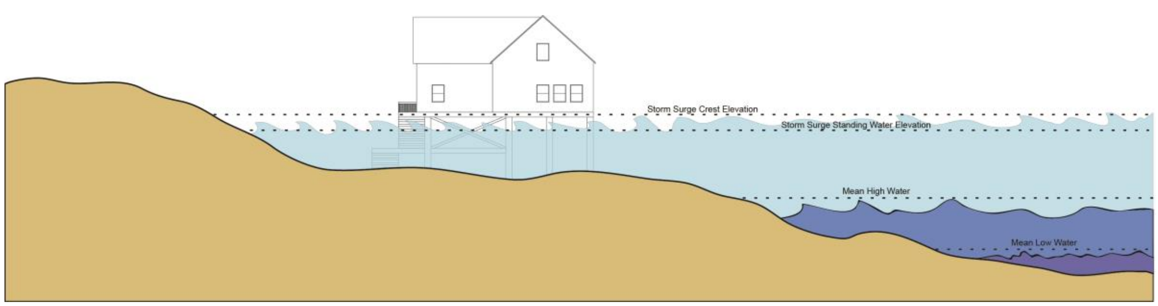

Figure 1.5 (Storm Surge Diagram)

[9] Stone, Brian. *The City and the Coming Climate: Climate Change in the Places We Live*.
[10] Blakely, Edward J., and Armando Carbonell. *Resilient Coastal City Regions: Planning for Climate Change in the United States and Australia*.
[11] Watson, Donald, and Michele Adams. *Design for Flooding: Architecture, Landscape, and Urban Design for Resilience to Flooding and Climate Change*

A warming climate and ocean is predicted to bring more intense storms with higher winds speeds and heavier precipitation.[12] The frequency of these storms is predicted to increase as well. "Even with a moderate sea level rise…extreme storms that are currently expected to occur every 100 years will begin to occur every several months." (Blakely, 32) This means that with the acceleration of frequency and intensity of storms, newly susceptible areas of inundation will likely have these vulnerabilities exploited often.

[12] Blakely, Edward J., and Armando Carbonell. *Resilient Coastal City Regions: Planning for Climate Change in the United States and Australia*

CHAPTER 2: *MEET TYBEE ISLAND*

HISTORY AND DEMOGRAPHICS –

The state of Georgia is not famous for its coastline or beaches, though Georgia's coastline is home to a variety of rare, complex, and robust ecosystems that are not matched anywhere else in the world. Moving south into the Florida coast or north into South Carolina's coast produces a much different picture, notably a less natural one. Of the 13 barrier islands that are found along Georgia's coast, nine remain in an undeveloped, natural state. Tybee Island is one of the four islands that have been developed by humans.[13]

When the Americas began to be colonized by Europeans these barrier islands were among the first places to be settled. Some were founded as townships, including Tybee Island. Many rather than becoming cities or towns, were inhabited in the form of isolated plantations that utilized slave labor. Sea cotton, rice, indigo, and sugar cane were the main crops grown by these plantations and the structures associated with this plantation development usually only included the residence of the owner, slave quarters, and storage facilities. No form of subdivision was associated with this type of ownership/development, and because of this fact there was no existing precedent or population to lead into full scale development. After slavery was outlawed, many of these plantation islands were purchased as resorts and get-aways by the emerging millionaires of industry and remained so throughout the early 20th century. As of today, all of the undeveloped islands have been repossessed or bought by the State of Georgia

[13] Andrews, Jill. "Georgia Department of Natural Resources Interview."

and are being preserved as natural habitats. Three of four islands which were established as townships and cities from the beginning continued their growth throughout these periods and remain active and vital parts of coastal Georgia's economy today.

Tybee Island, seen in Figure 2.1, is both an island and a city. It is located in Chatham County, Georgia 18 miles off of the coast of Savannah, and is accessible by U.S. 80.[14] Tybee Island is located just south of Hilton Head Island and serves as the only accessible beach on the northern coast of Georgia, the next closest being St. Simons Island which is a 2 hour drive and 100 miles further south. This location helps the beach on Tybee to play a vital role in the success of the economy and livelihood of the citizens of Tybee.

[14] McKee, Gwendolyn. *A Guide to the Georgia Coast*.

Figure 2.1 *(Near Infrared Satellite Image of Tybee Island)*

Tybee Island has been an important locale since the establishment of the colony of Georgia. Tybee Island was founded in 1733 by the founder of Savannah, James Oglethorpe. The historic lighthouse on Tybee Island was the third one built in America and guided British ships into safe harbor. The island also was a haven for pirates who harried the coast at that point in time. One of the more notable villains was Black Beard, whose treasure is still thought to be buried somewhere on the island. Later on, the island was a gathering point for the French fleet during the Revolutionary War.[15] This island is rich in history and culture, and currently is a place of leisure and vacation, with a year-round population of 2,990 which swells to 25,000-35,000 during the summer (Wolff interview).[16] Whether it is the robust economic role it plays or the sheer numbers it boasts during peak seasons, Tybee Island is considered a vital component to the economy of Chatham County and coastal Georgia.

The constituents of Tybee Island do not consist of tourists or inordinately wealthy people despite the island's status as a tourist destination. This 1000% increase from a population of 2,990 to 30,000 is a testament to the vitality of the appeal of Tybee Island as a vacation destination.[17] Of the population estimate of 2990 by the 2010 census, 94% is white. This population count is approximated to be 93.5% white.[18] According to an interview with a city-council member, the population swells to approximately 30,000 in the summer season. That same year round population of 2,990 is 65.3% 18-64 year olds, which demonstrates that the citizens of Tybee island are not simply retirees or young families, but a population that is well within the working class. The average per capita income is $37,667.[19] Regarding the development of Tybee Island, only 23% of

[15] McKee, Gwendolyn. *A Guide to the Georgia Coast*.
[16] Wolff, Paul. "Tybee Island City Council Member Interview."
[17] Wolff, Paul. "Tybee Island City Council Member Interview."
[18] "Census Bureau Homepage." *Census Bureau Homepage*
[19] "Easy Stats." *Easy Stats*. United States Census Bureau

the island's parcels are undeveloped. There are 3697 parcels available for ownership on Tybee Island, and the total real estate value of these 3697 parcels is $2,066,167,830. Most of Tybee Island is zoned residential, with 88.4% of the parcels being of that distinction. A few beach front clusters and a corridor are available for commercial development.

These statistics prove to be helpful in gaining insight into the makeup of the City of Tybee Island. The community is not one of retirees or of people of great wealth. Tybee Island is constituted of mainly blue collar workers who live there year round and often make part of their living off the enormous influx of visitors during the summer season. Tybee Island also has an important relationship to the historic city of Savannah, going as far as their beach being referred to as "Savannah Beach". Tybee Island's culture and the lifestyle of those living there is slow paced, southern, cozy, and tropical. The community is that of a warm little beach town where vacationing millionaires rub elbows with the local handy man at a bar on a Friday night. The laid back attitude of the inhabitants pervades throughout the island to many of the occupations and lifestyles pursued there.

Tourism is a vital part of Tybee Island's economy and without it the Island would cease to function. Charter fishing, paddle/surfboard rentals and lessons, kayak/canoe rentals, and bike rentals are simple examples of some livings people make off the tourist season. Many inhabitants rent their homes out to vacationers, run/work at restaurants and bars, or operate some sort of commercial place of business or art gallery. The vitality tourism brings to the island's economy cannot be overstated, nor can its link to Tybee's beach. The real estate sector, retail trade, accommodation, and food services are where the high percentages of employment are located. Combined, those three occupations account for 34.7% of those employed on the island.[20]

BARRIER ISLAND FORMATION –

The barrier islands of coastal Georgia have, over about 10,000 years allowed the development of unique ecosystems that harbor a variety of species and life forms.[21] The ecosystems present on a barrier island generally include the following: ocean, beach, dune, maritime forest, marsh, and estuary.[22] All of these are vital ecosystems to the barrier island's existence. The formation of the ecosystems and the formation of the islands themselves are inextricably linked. The islands began to form during and due to the initial phases of the ecosystems existence, and the islands beginning to take hold allowed the ecosystems to further develop in number and complexity. The last global sea level rise (known as the Holocene transgression, marked the transition out of the last ice age about 10 000 years ago. What are current day barrier islands then existed as a sand dune ecosystem.

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[20] "Easy Stats." *Easy Stats*. United States Census Bureau
[21] Pilkey, Orrin H. *The North Carolina Shore and Its Barrier Islands: Restless Ribbons of Sand*.
[22] Andrews, Jill. "Georgia Department of Natural Resources Interview."

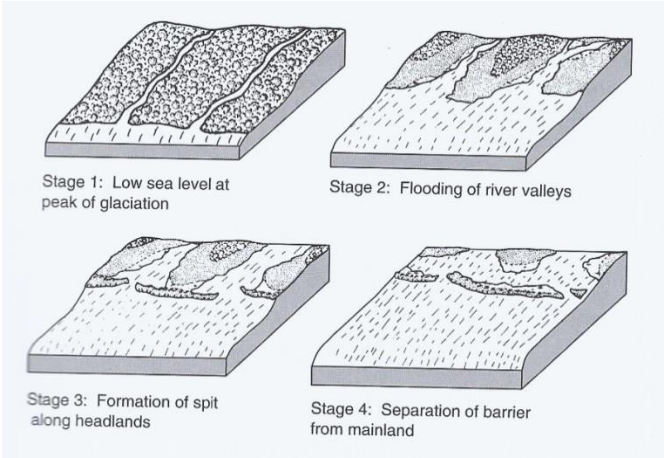

Figure 2.2 *(section showing current day barrier island as a dune transitioning into island)(Pilkey, page 43)*

When the sea level began to rise during this period the rising water encroached upon the dune system. The water was able to get around the dune system, creating a lagoon on the landward-side thus isolating the then dune as an island. Once this occurred further gradients of ecosystems were able to develop to create an island biome. Rather than remaining as a permanently beached off-shore sand bar, accretion, deposition, and erosion began to work to create a beach ecosystem on the seaward side of the now island and a marsh/estuarine system on the landward side. The high ground in the middle of the island was able to accrete an aggregate less peaty and clay-like than the estuarine side and less sandy than the beach side. This soil, sometimes referred to as dune-bedding, enabled the growth of grasses, shrubs, and eventually hardwood and tree species that create maritime forests.[23]

Once these islands were established and the ecosystems upon them formed, they did not remain static. A curious characteristic of barrier islands is that they naturally

[23] Pilkey, Orrin H. *The North Carolina Shore and Its Barrier Islands: Restless Ribbons of Sand*.

migrate.[24] This migration is a natural result of sea level rise, and occurs landward towards more shallow waters. Sand erodes from the seaward side of the island as it accretes on the landwards side of the island. If the middle of the island is able to remain above sea level as it rises, then the island seems to move towards the land over time. On North Carolina's barrier islands there are certain occurrences of "find(ing) the shells of oysters, clams, or snails that once lived in the estuary behind the barrier island" on the beach. This phenomenon is explained by the island's having "migrated across the estuary, and open ocean waves attacking and breaking up the old estuary sands and muds, now exposed on the shore face, (throwing) up the shells onto the beach." (Pilkey, 43) The barrier islands of coastal Georgia all this marsh ecosystem on the landward side of the island leading into a lagoon, bay, or river mouth. This ecosystem holds a significant economic value for human settlements, as does the beach front on the opposite side of the island. The maritime forest and center of these barrier islands is usually on higher ground and is often suitable and desirable for human habitation. This is evident on the developed barrier islands of coastal Georgia through the presence of human development where the maritime forest should be. Human habitation eliminated this transitional ecosystem leaving only two other vital ecosystems, the beach and the marsh. F

SLR AND DEVELOPED BARRIER ISLAND ECOLOGIES –

When an island like Tybee is developed with hard infrastructure, the prospect of flooding seems much more critical. The marshes on developed islands will be some of the first victims of sea level rise. Marshes are a significant component and asset to

[24] Pilkey, Orrin H. *The North Carolina Shore and Its Barrier Islands: Restless Ribbons of Sand*.

coastal ecosystems, and their loss would be significant. Marshes act as buffers in several different capacities such as between land and coming storm surge, inundation, wave action, and between the sea and runoff and pollution from development. Marshes are also nurseries for several different species of fish, shellfish, birds, and they harbor dense vegetation growth which have other desirable qualities..[25] "Wetland soils and vegetation contribute to greenhouse gas (GHG) mitigation through intense productivity. These wetlands retain, recover, and remove excess nutrients and pollutants from stormwater, and they also aid in soil formation and nutrient recycling, providing a broad diversity of habitat for resident and migrating species. Beyond that, they stabilize shore-lines by reducing erosion, dampen storm surges, dissipate strong winds, protect against flooding, and reduce damage to life and property during severe storms" (Blakely, 34)

It is the existence of development and shore armoring coupled with elevated sea levels which will pose the greatest threat to the existence of the marsh. If only sea level rise was confronting the marshes, their destruction would not be assured. Salt marsh ecosystems are naturally able to migrate or "creep" with rising sea levels. "Salt marshes have been seen to alter their elevation relative to sea level by trapping sediment loads and accumulating vegetative detritus. Under certain conditions, salt marshes may be able to keep ahead of rising sea levels through a process of accretion…If sea level rise occurs at a slow rate, a marsh will both elevate itself and migrate slowly inland." (Blakely, 35) Marshes will be able to creep inland and preserve themselves so long as the sea level does not rise more than 1.2 centimeters per year. Despite the ability for a marsh to self-regulate through accretion, bulkheads, seawalls, and other shore stabilizing methods serve as a barrier to marsh accretion. When there is a hard shore stabilizing infrastructure, rather than allow the marsh to accrete and

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[25] Andrews, Jill. "Georgia Department of Natural Resources Interview." Personal interview

creep, the wall serves as an impediment for further displacement of the marsh and it essentially drowns with the rising sea. Demonstrating the significance of this process and human development's role, Figure 2.3 shows the location of all hard shore stabilizing infrastructure on Tybee Island, key points that will be the future bottle necks for marsh creep and the sites of "dead zones".

Much like the marshes on the opposite side of the island, beaches are naturally dynamic ecosystems which have their own processes for dealing with storms which are altered when human habitation becomes a variable. This dynamic process by which a beach self-regulates depends on four variables: wave energy, the type of beach sand, the shape and location of the beach, and the rate of sea level change. [26] "The beach maintains a natural balance referred to as a 'dynamic equilibrium' of the above four factors. When one of the four factors changes, the others all adjust accordingly to maintain the balance. When humans enter the system and oppose the status quo of natural processes, the dynamic equilibrium continues to function predictably, but in a way that damage or destroys buildings and infrastructure." (Pilkey, 55) When undisturbed beaches will, in facing storms, sea level rise, etc., self-regulate to remain intact, often appearing in the form of island-migration or beach-flattening. Human habitation of beaches disrupts this process.

Much like with marsh creep, human development impedes the accretion and deposition of sands, silts, and sediments that allows a beach to creep inland. This fact is already a reality for Tybee Island. The beach on Tybee Island is presently required to be "re-nourished" every seven years.[27] The beach is eroding every day, without the

[26] Pilkey, Orrin H. *The North Carolina Shore and Its Barrier Islands: Restless Ribbons of Sand*
[27] Wolff, Paul. "Tybee Island City Council Member Interview.".

compensation of accretion on the opposite side of the island or dune build up. Human development serves as a dead end for the beach, as it serves for the marsh creep.

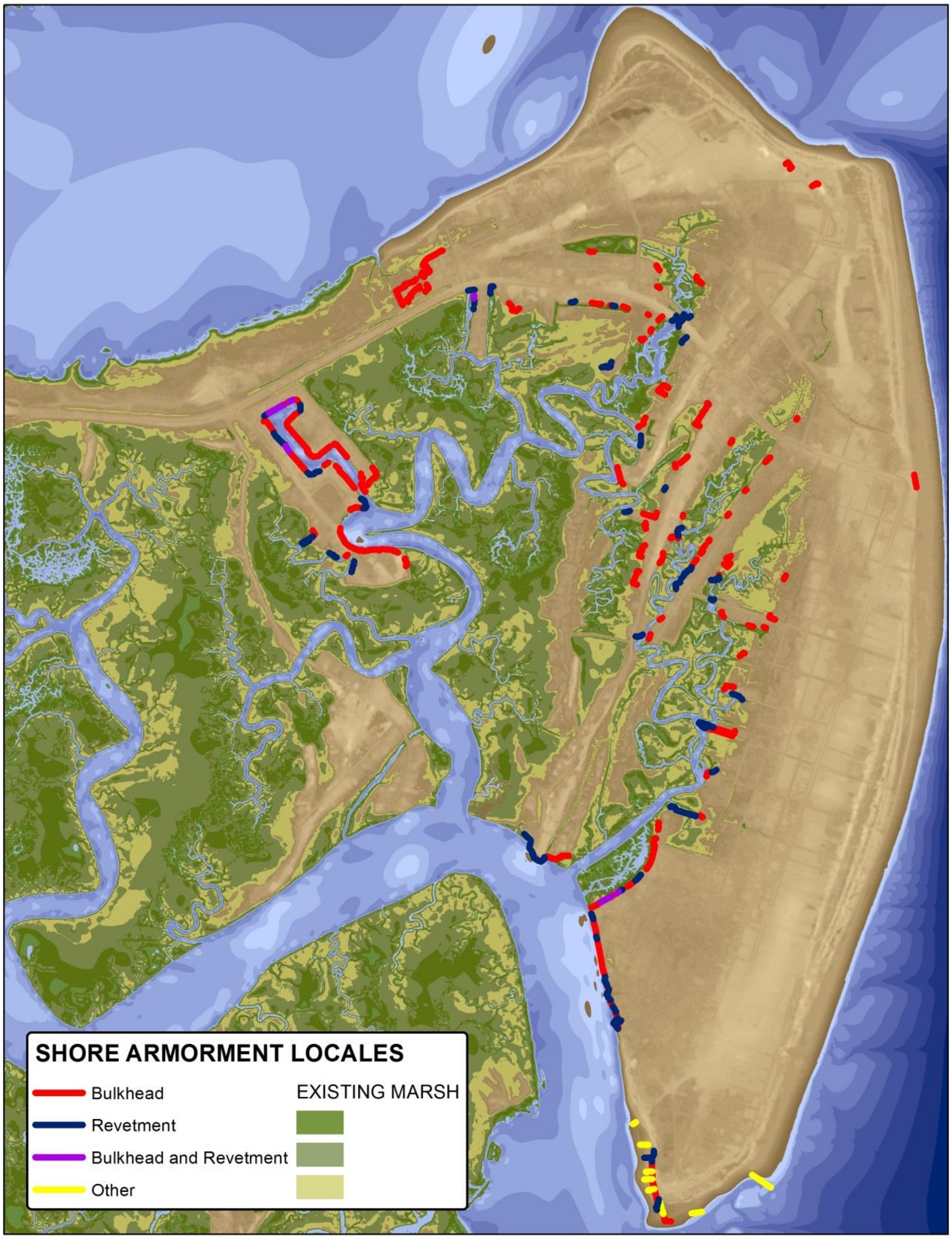


Figure 2.3. *(existing instances of Shore Armament on Tybee Island)*

This results in the disappearance of Beaches and Islands and because of this, sand is brought in from dredge spoils and other locales[28] and dumped onto Tybee's beach, to build it back up every seven years so that it can be enjoyed by the citizens and visitors. This practice is not a very sustainable habit and costs about $19,000,000 for each instance. Beach erosion is the main detrimental side effect of SLR in regards to barrier island beaches. Beach erosion occurs at a rather high rate which is directly proportional to the rise in sea level. The "Bruun rule" theorem elaborates on this rate. "The Bruun rule posits that the extent of landward beach-profile recession will be from 50 to 100 times the rise in sea level; thus, for every meter of increase in sea level rise, beaches will recede by 50 to 100m." (Blakely, 34) This problem is a very serious consequence to sea level rise whose economic implications must be taken into consideration.

SLR AND DEVELOPMENT ON BARRIER ISLANDS –

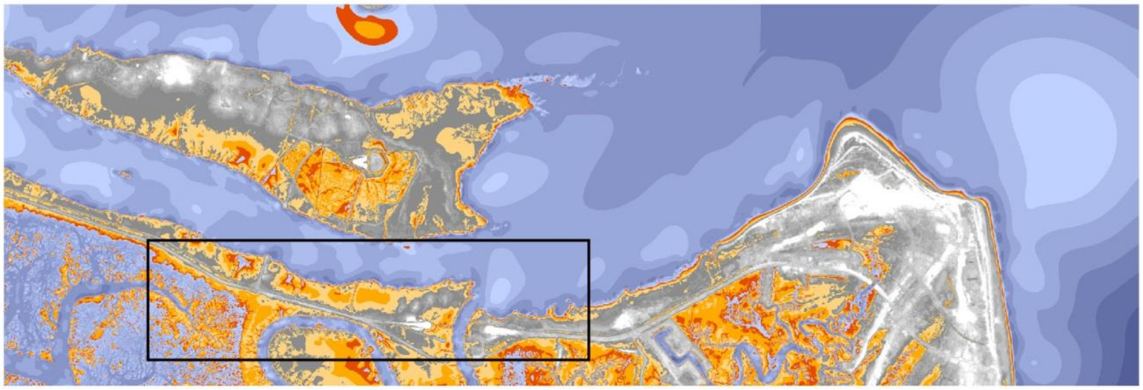
Flooding is going to be the most tangible and prioritized risk for many of the citizens of Tybee Island. The causeway that accesses the island, the infrastructure of the island, and the homes on the island are at risk and are going to receive the most damage when flooding occurs. As of today, Highway 80, the only road leading on and off the island, floods about five times a year due to high tide and storm surge events. With one foot of sea level rise, this frequency of flooding will increase to 85 times per

[28] Andrews, Jill. "Georgia Department of Natural Resources Interview."

year.[29] This potential event is a serious cause for concern as it is the only way to get on and off of the island in a terrestrial vehicle. At some point in time, unless remediation is instituted, the causeway will be completely underwater at high tide every day. The precarious positioning of the causeway in relation to the mean high tide level is demonstrated in Figure 2.4. The grey-scale massing is the island, and the red, orange, and yellow colors indicate elevations of 0-1', 1-2', and 2-3' respectively. The narrow band sandwiched between these low lying areas is the causeway leading off the island. If there were an unusually high tide coinciding with an elevated sea level of 3 feet due to the presence of a storm, breaking waves would easily flood the causeway, prohibiting vehicular traffic. The implications of this could be devastating for Tybee Island, limiting access and economic viability. The causeway, being the most susceptible to flooding, is only a harbinger of the coming susceptibility of the entire infrastructure on Tybee Island. Not only will the pavement be susceptible to flooding, but the ground water pipes, sewage pipes, wells, and treatment facilities will be at risk. If the outlets for storm pipe networks are flooded, the mainland will be flooded with rain. Even more of an issue is that this pipe infrastructure can lead to backflow flooding problems.

The infrastructure susceptibility and damage is only the beginning of the property damage/loss to be experienced with rising sea levels on Tybee Island. The loss of structures and property will be a devastating blow to the civilians and the economy of Tybee. The total real estate value of the 718 parcels on Tybee Island that will have at least some portion of their property inundated at least once a day at high tide with +01-03' of sea level rise is $400,156,210. The total real estate value of the 1,727 parcels on the island that will have at least some portion of their property inundated with +04-06' of sea level rise is $891,839,100. Figure 2.5 shows the figures in relation to each other.

[29] Wolff, Paul. "Tybee Island City Council Member Interview."



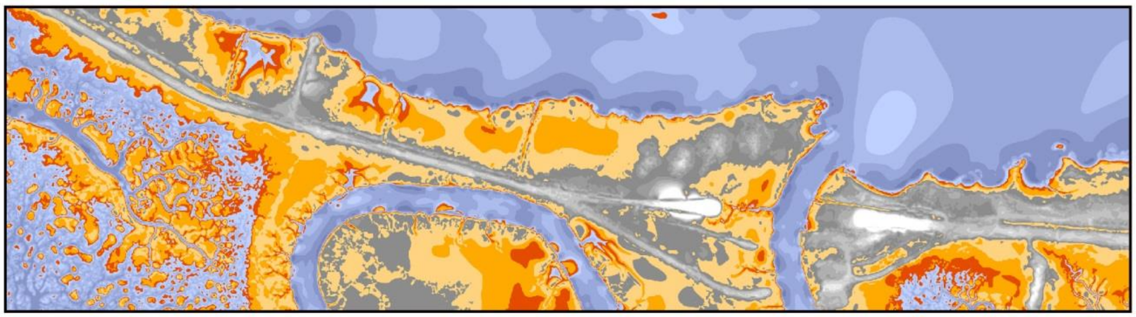


Figure 2.4 *(Causeway Susceptibility at +0-3' SLR Above Mean High Tide)*

Sea Level Rise	# of Parcels at Least Partially Inundated	Real Estate Value	Land Value	Building Value
+01-03'	718	$400,156,210	$314,524,490	$85,631,720
+04-06'	1727	$891,839,100	$596,558,917	$295,280,183
+07-09'	992	$610,445,000	$313,093,724	$297,351,276
+10-12'	209	$138,780,510	$70,421,510	$68,359,000
+13-15'	31	$18,654,010	$9,987,010	$8,667,000
TOTAL (+01-15')	3677	$ 2,059,874,830.00	$ 1,304,585,651.00	$ 755,289,179.00

Figure 2.5 *(Parcel Statistics Based on Minimum Elevation within Parcel)*

Figure 2.6 shows a graphical representation of the minimum elevation associated with the parcels on the island. Assuming that the sea level only rises three feet in the coming century, this devalues close to 400 million dollars in real estate and renders an additional ~900 million dollars in real estate value highly susceptible to a meager three feet of storm surge that occurs roughly five times a year in today's climate, and which is predicted to occur more frequently in the future. The Federal Emergency Management

Agency (FEMA) has had its own response to these predictions and the resulting implications of the coming climate.

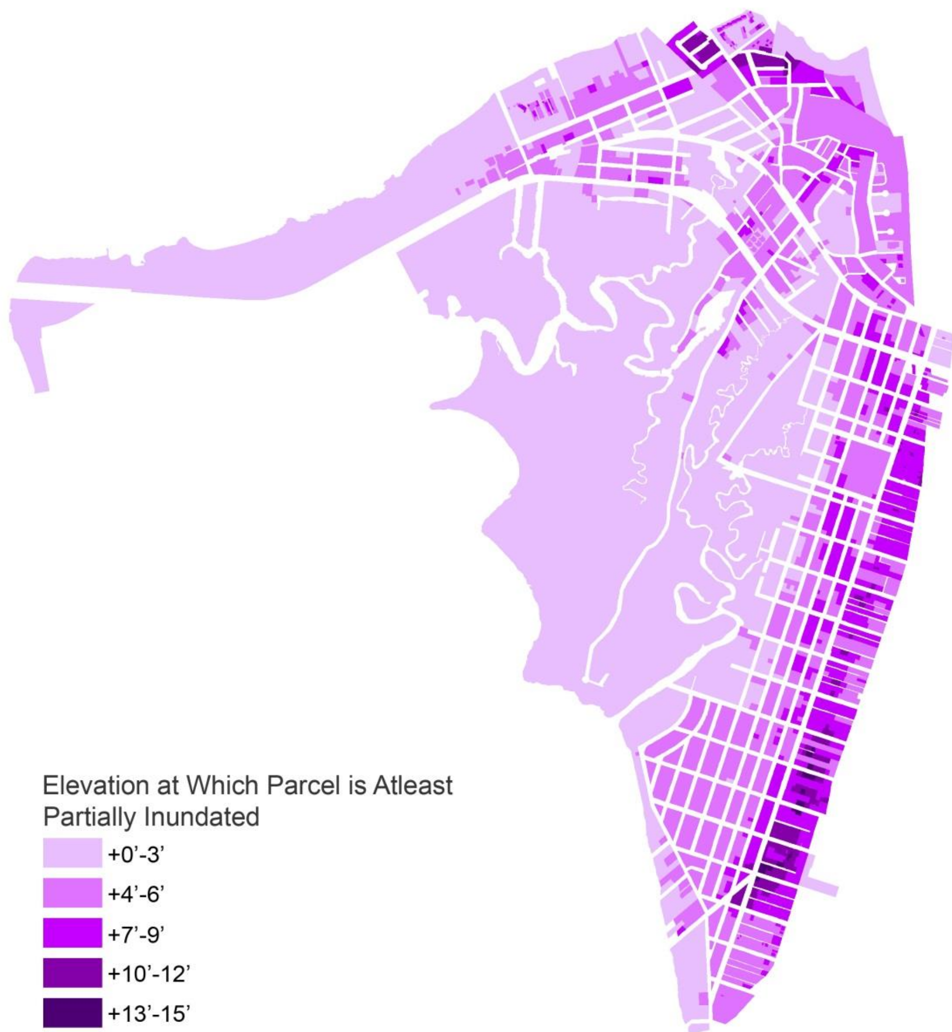


Figure 2.6 *(Partial Parcel Inundation based on Minimum Elevation)*

FEMA is in charge of gaining and granting subsidies in order to publicly fund flood insurance, establishing guidelines for the administration of this insurance, and promoting smart and resilient planning for flood events for people living in coastal cities and towns. The agency uses a National Flood Insurance Program (NFIP) to achieve these duties.[30] The standards, rules, regulations, rates, and other components of the flood insurance program are described more fully in FEMA's Flood Insurance Manual (FIM). An accessory to this manual that outlines specifics "zones" for specific areas dictating levels of risks and associated rates are a series of maps known as Flood Insurance Rate Maps (FIRM). These FIRMs delineate the boundaries which assign homes and structures to differing "zones" which each imply a certain rate. Tybee Island is entirely in the 100-year flood plain and home to two distinct zones out of the many that are housed in the FIRMs. These zones are "AE" and "VE". Differing categories of these types of zones exist within the FIM, the distinguishing characteristic being the severity of the risk of a flooding hazard.

Both the AE and VE zones found on Tybee Island fall in the "Special Flood Hazard Areas", which are the most severe areas. The AE zone dictates that people applying for National Flood Insurance must report the elevation of the lowest floor to the agency and a Base Flood Elevation is specially dictated by FEMA. The VE zone is "an area that is inundated by tidal floods with velocity (coastal high hazard area.)"(FEMA FIM, 421) and a site specific Base Flood Elevation is dictated. A base flood elevation (BFE) is diagrammed in the following Figure 2.7. A BFE is defined as "indicat(ing) the 100-year Stillwater elevation predicted for riverine flooding and the wave crest elevation for coastal flooding….To determine BFE FEMA computer modeling computes…maximum wave heights and, in some areas, maximum wave run-up, whichever is greater." (Watson, 143) The BFE is site specific for each home/structure for which someone is seeking a premium and, though not all flood zones require a

[30] United States of America. Federal Emergency Management Agency. National Flood Insurance Program. *FEMA*.

dictated BFE, the zones present on Tybee require the BFE to be met in order to be insurable.

Figure 2.8 shows the current zone delineations on Tybee Island. FEMA has already assessed the topography of Tybee, created maps, and established requisite BFEs for owners seeking flood insurance premiums. Figure 2.8 is a graphical representation of theses BFEs. The closer you are towards the center of the island, the lower your BFE is. One risk with sea level rise is that with each foot, the pre-existing BFE that was calculated to drastically reduce the risk of flood damage on a home or property, is made obsolete. Even more complicating is that when looking at sea level rise on a larger scale, say three feet of rise, the eroding beach and flooding marsh may render the current zones obsolete, effectively transforming AE zones into VE zones. These foreseeable complications in current flood insurance regulations and the rising sea have already and will continue to force FEMA to impose more strict regulations, higher premiums, and more uninsurable properties.

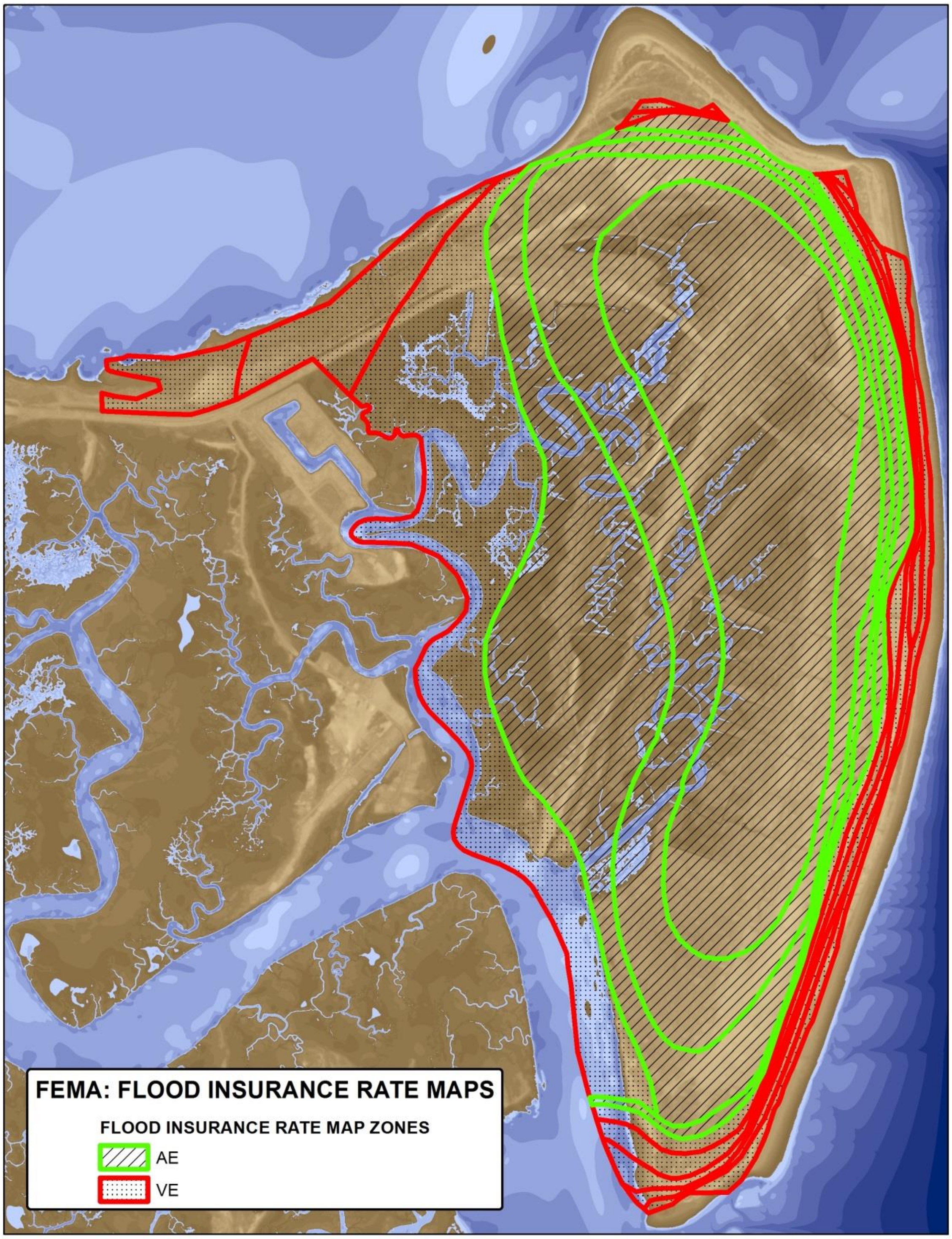


Figure 2.7 *(Zone Delineations on Tybee Island)*

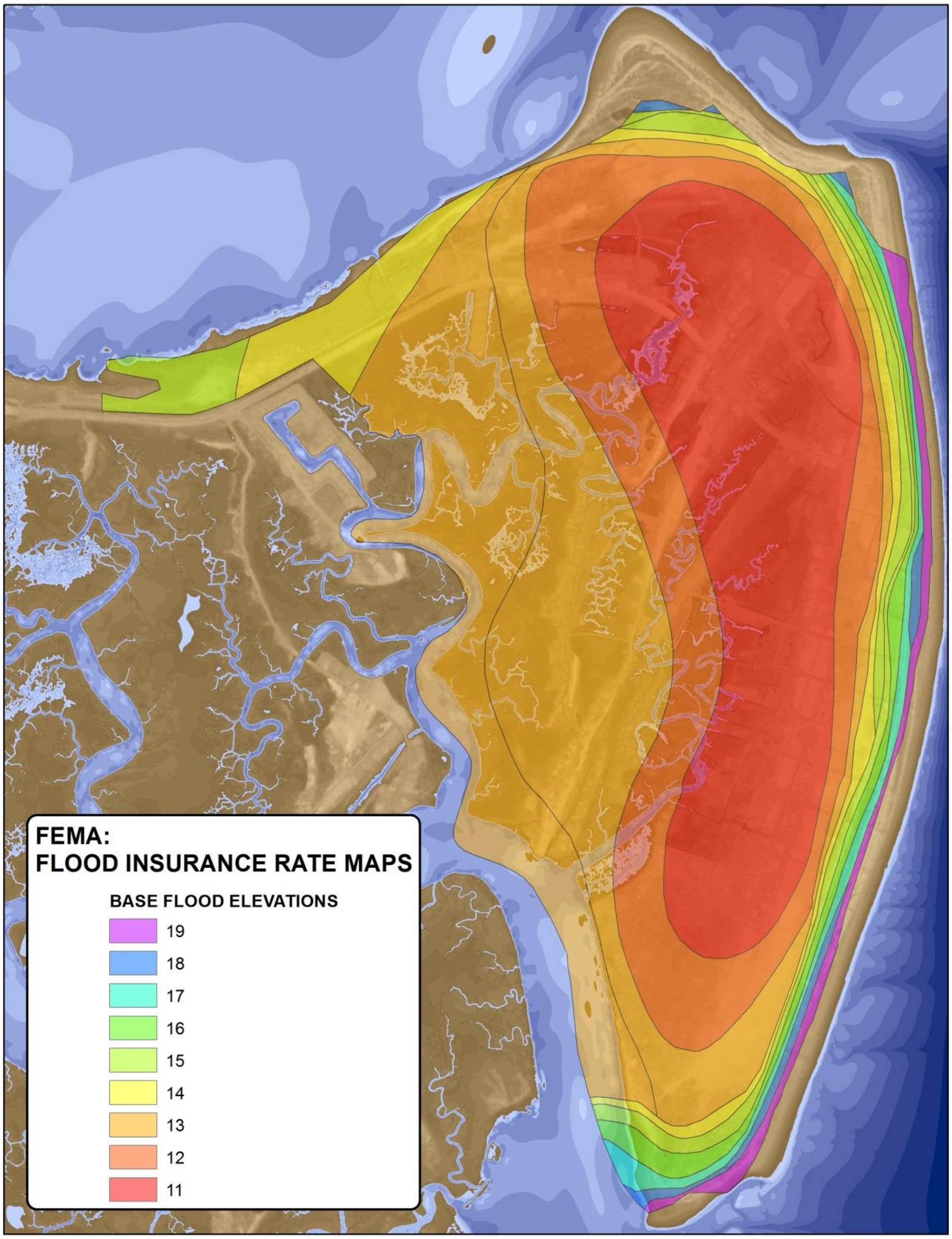


Figure 2.8. *(Diagram displaying structural BFE impositions)*

CHAPTER 3: *TYPICAL TACTICS*

TYBEE HAS A PLAN –

When faced with the threats and implications of sea level rise there are three categories under which most responses fall: retreat, accommodate, and protect. A plan of "retreat" would be to "abandon structures in currently developed areas, resettle the inhabitants, and require that any new developments be set back specific distances from the shore." (Beer, 49) "Accommodation" involves accepting the greater levels of inundation and flooding expected to occur, and shifting values, processes, and cultures to incorporate this into daily life. An example of an accommodation strategy would be to capitalize on switching to aquaculture rather than vegetable crops.[31] The third category of "protect" is to defend current lifestyles from the threats associated with sea level rise. This category means to build walls, stabilize shorelines, elevate structures and infrastructures above expected inundation levels, and a general defense of populated areas, vulnerabilities, infrastructures, and ecologies. These tactics and how they apply in different ways to common vulnerabilities is represented in figure 3.1. Most current Sea Level Rise plans can be categorized into one of these three subdivisions.

[31] Beer, Tom. *Environmental Oceanography*

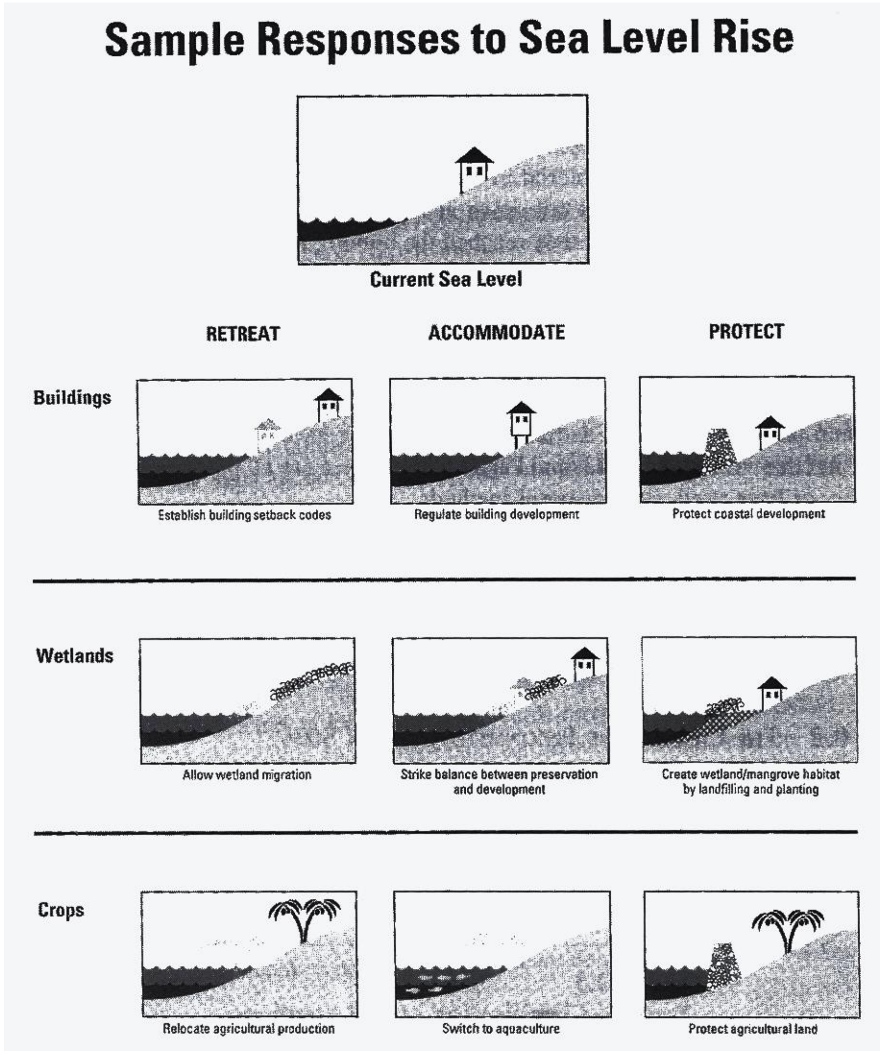


Figure 3.1 *(Diagrams showing differing effects of 3 categories) (Beer 51)*

Tybee Island has already been the subject of attention by groups who have proposed Sea Level Rise Adaptation Plans for the island. The NOAA Sea Grant has recently funded a Sea Level Rise Adaptation Plan for the city of Tybee Island, in affiliation with the Georgia Sea Grant, the Carl Vinson Institute of Government, and the City of Tybee Island. This report was compiled by a variety of PhD students and specifically looks at many problems addressed in this thesis, with subtle nuances and focuses in different areas. The report "TYBEE ISLAND: Sea Level Rise Adaptation Plan" has outlined six potential adaptation actions to be undertaken to prepare for the coming changes in sea levels as they effect Tybee Island. The six actions listed by the report are: Stormwater Retrofit, Elevating Well Pumps, Repetitive Loss Properties, US 80, Beach Nourishment, and Shoreline Stabilization.

THE PLAN –

The “Tybee Island Sea Level Rise Adaptation Plan” has asserted six actions to be undertaken in order to prepare for the future rising sea levels, though only four of the six actions are pertinent to this thesis proposal. The four actions that will be focused are: Stormwater Retrofit, Repetitive Loss Properties, Beach Nourishment, and Shoreline Stabilization.

The first action to be taken in the adaptation plan is “Storm Water Retrofit” which addresses drainage and runoff problems on the island. Tybee Island’s grade differential between the lowest and highest elevation is very low (+1’ - +15’), which means that the island has areas with a low slope which causes runoff problems. This low slope and much of the developed soil being marshland with poor infiltration[32] subjects many areas to flooding from heavy rains. This problem is exacerbated by back-flooding of the storm pipe network. This occurence is demonstrated in figure 3.2 below.

[32] Wolff, Paul. "Tybee Island City Council Member Interview."

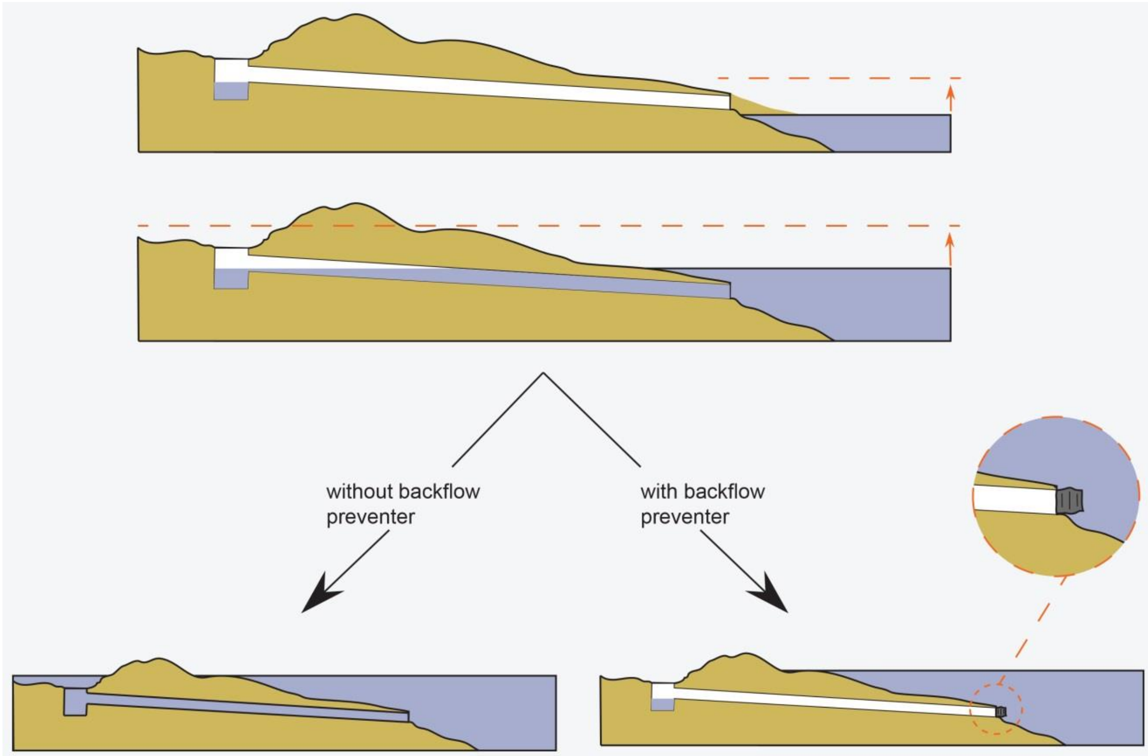


Figure 3.2 *(diagram showing backflow through stormwater pipe)*

To combat this typical occurrence, the city has funded the retrofitting of these pipes. A "backflow preventer" is fitted to the pipe, allowing regular discharge when necessary, but preventing the sea from back flooding the mainland as the water level rises in the presence of a storm, shown in Figure 3.3 below. The Tybee Island Sea Level Rise Adaptation plan calls for a prioritization of when discharge points need to be retrofitted and that other retrofit options need to be evaluated.[33]

[33] Evans, Jason, Rob McDowell, Chuck Hopkinson, Jill Gambill, David Bryant, Kelly Spratt, and Wick Prichard. *Tybee Island Sea Level Rise Adaptation Plan*

Figure 3.3 *(Backflow Preventer Retrofit preventing backflow on Tybee Island)*

The second action listed in the Tybee Plan is to mitigate the repetitive loss of property. The approach listed to prevent damage and loss of property is to improve the community rating with FEMA's "Community Rating System". The Community Rating System (CRS) is defined in the FEMA Flood Insurance Manual as "a voluntary program (whose) goals…are to reduce flood damages to insurable property, strengthen and support the insurance aspects of the NFIP, and encourage a comprehensive approach to flood plain management. The CRS has been developed to provide incentives in the form of premium discounts for communities to go beyond the minimum floodplain management requirements to develop extra measures to provide protection from flooding." (Flood Insurance Manual, CRS1) Homes and structures to benefit from the CRS, must first be in compliance with the standards established by FEMA in order to qualify for flood insurance. Once eligible, there are 10 different classifications within the CRS which establish certain criteria which need to be adhered to in order to for a community to qualify for benefits. This criterion relates to issues regarding Public Information, Mapping and Regulation, Flood Damage Reduction, and Flood Preparedness.[34] The benefits range from a 5% to a 45% reduction in each specific flood insurance premium. The plan calls for the continuance of pursuing CRS qualifications.

Beach nourishment marks the third action to be undertaken in the Tybee plan. The Tybee Beach is already under a schedule of nourishment every seven years, and this point of action recommends the continuance of the current nourishment practices. Current practice is that 12 feet of sand is added to the beach at the seaward edge of the dune field and is tapered back down to the water line.   The nourishment process raises the beach, minimizing the scouring effect of the wave energy.[35] Without this process, there is no beach, and without a beach there can be no economy. This point of action not only recommends a continuation of current nourishment practices but encourages periodic evaluation of whether the volume or frequency needs to be increased in response to changes in SLR.

The final action suggested by the Tybee Plan is “Shoreline Stabilization”. The plan suggests that while typical armoring tactics such as seawalls and bulkheads are effective, new and innovative methods in coastal armoring should be evaluated so that the stabilization of shorelines can be done in a way that is not harmful to local ecologies nor as expensive as bulkheads or seawalls. There are several sites of coastal shore armoring existent on Tybee, most of which are on the landward marsh side of the island. Figure 3.4 shows the location of these coastal armoring structures. These structures,

[34] United States of America. Federal Emergency Management Agency. National Flood Insurance Program

[35] Wolff, Paul. "Tybee Island City Council Member Interview."

though already in place, have been proven to be detrimental to local ecologies. The action proposed by the plan urges a comprehensive policy strategy to be adopted to regulate these armoring projects.

A CRITIQUE –

The Sea Level Rise Adaptation Plan for Tybee Island has evolved throughout a series of workshops that involve citizen and community feedback,[36] and their voice is embodied in this plan. These constituents of Tybee Island may not be aware of the long term consequences of the planning decisions they play a role in making. When faced with a threat to property and life, the two immediate choices are to fight or flee. It makes perfect sense that a sea level rise adaptation plan informed by those whose property is at risk is not an adaptation plan at all; rather it is a defensive plan. This defensive plan for Tybee Island to face coming SLR is not comprehensive it is piece-meal focusing on strengthening dissociated assets and defending them against SLR. The island and its ecosystems will be collateral damage of this defensive planning mindset.

The first action of the plan is retrofitting all the storm water pipes with backflow preventers at their discharge points. The city is devoting about $18,000 to each back flow preventer[37], and the Tybee Plan calls for a continuation of this policy. The plan asserts that the future retrofitting of the discharge points needs to be prioritized and that different options and sustainable mechanisms need to be evaluated and researched.[38] This method is effective at preventing back-flooding at the current sea level, though it is

[36] Evans, Jason, Rob McDowell, Chuck Hopkinson, Jill Gambill, David Bryant, Kelly Spratt, and Wick Prichard. *Tybee Island Sea Level Rise Adaptation Plan*.
[37] Evans, Jason. *Sea Level Rise Adaptation Planning in Tybee Island, Georgia*.
[38] Evans, Jason, Rob McDowell, Chuck Hopkinson, Jill Gambill, David Bryant, Kelly Spratt, and Wick Prichard. *Tybee Island Sea Level Rise Adaptation Plan*

purely defensive strategy. If current projections hold true, a minimum of half the 47 discharge points would need to be retrofitted. Based upon a Spatial Join Analysis using municipal data regarding Tybee's storm water infrastructure, 42 of the 47 discharge points are located within +2' - +5'. Five additional discharge points lie below +2'. If the average projections by the IPCC's AR5 prove to be true ~51% of the discharge points will be underwater during normal high tide, with a remaining ~47% of the discharge points being at risk to a mere 2' of storm surge or above average high tide events. This means that Tybee will have to spend time and money on a storm water infrastructure that will be only 50% operable high tide every day, and 98% inoperable during storm events that are accompanied by +2' of storm surge. The irony is that this infrastructure will be at risk of 98% inoperability during storms when it is needed most to drain rainfall from the marsh-like soil in flood-prone areas.

The next action is to focus on mitigating flood damage to property and buildings by improving the Community Rating System level among the homes on the island. This action is moving in the right direction, but not going far enough. FEMA's community rating system has certain criteria and requirements for boosting CRS ratings and most of these do indeed mitigate damage done by flooding events. The requirements ranging from going above and beyond Base Flood Elevation requirements, community education and awareness, and familiarity and publication of Flood Insurance Rate Maps all help to prepare communities for flood events, yet the CRS is a program for defending against SLR and storm events. When limited to the bounds of what will achieve credit with FEMA, a variety of innovative design strategies and options are left out which could prove to have an immeasurable positive impact on Tybee communities.

The third action calls for a continuation of the $17 million nourishment of the beach on its seven year cycle and consistent evaluation of whether the current practices need to be altered to fit demands of a more extreme erosion of the beach. This strategy is a defensive one which assumes that a constant recalibration (tending towards an increase) of human intervention will solve the problems posed by SLR. Assuming that the beach erosion problem can be fixed forevermore by a constant alteration of nourishment practices prevents the conception of a more sustainable solution. At one point in time if the rates of erosion continue on their current trend, there won't be much of a beach to nourish.[39] As the sea level rises, the beach will continue to narrow to a point where it might not make fiscal sense to continue the multimillion dollar nourishment procedures. "The Bruun rule posits that the extent of landward beach-profile recession will be from 50 to 100 times the rise in sea level" (Blakely, 34). At its widest, the Tybee beach is about 300 feet from high tide mark to the most seaward dune. According to the Bruun rule, only three feet could move the high tide mark between 150 feet and right up to the edge of the existing dunes system.[40] Nourishment will not help much in this scenario. When it is understood that a plan of continual beach nourishment is not a long term or sustainable solution to beach erosion, a truly innovative and adaptive plan will emerge which will continue to be effective at high levels of sea level rise.

The fourth and final action is the stabilization of the shoreline. This point calls for the development of policy to regulate shore stabilization and the development of more ecosystem friendly stabilization options. While shoreline stabilization may be the most economically feasible and readily effective way for inhabitants to protect their homes from rising sea levels, this stabilization will have drastically negative impacts for the island as a whole. Any sort of stabilization, hard infrastructure, or human interference that prevents the marshes from being able to migrate with rising seas, which occurs

[39] Wolff, Paul. "Tybee Island City Council Member Interview."
[40] Blakely, Edward J., and Armando Carbonell. *Resilient Coastal City Regions: Planning for Climate Change in the United States and Australia*

naturally so long as the rise does not exceed 1.2 centimeters per year. The marsh is able to do this through a process of accretion. Marshes have also been known to migrate inland though trapping sediment loads and accumulating vegetative detritus. Through these processes, the marsh is able to elevate itself and migrate inland along with the high tide mark.[41] If there is a sea wall or some other man-made impediment that blocks this process of accretion and elevation, the marsh will not receive the proper amount of dry time with the new sea level and will drown. The ironic thing about how shore stabilization tends to kill marshes is that marshes are a natural and superior form of shoreline's stabilization. The problem with using a marsh as a stabilizer is that the marsh will not remain in desirable positions such as at the edges of private property. Regardless, marshes stabilize and reduce erosion, absorb storm surge and flooding, dampen offshore winds, protect against flooding, and generally mitigate flood damages to people, property, and places. Through the process of man-made shore stabilization, not only will Tybee lose ecosystem's value to the economy and ecology of the island, but it will lose the best shore stabilizing system that naturally migrates to where shore stabilization is needed most (regardless of whether or not it is in the middle of someone's backyard).

[41] Blakely, Edward J., and Armando Carbonell. *Resilient Coastal City Regions: Planning for Climate Change in the United States and Australia*.

CHAPTER 4: *A NEW PLAN*

INTRODUCTION –

Tybee Island has three options. The first is to completely abandon the island and to let nature reclaim it. The second is to against nature, using every technological means to curb the threats of sea level rise. The third option is to learn to live with the rising seas. We can run, fight, or adapt. The negative consequences of a defensive strategy were covered in the previous chapter, but generally encompass detriment to the ecological well-being of the place being planned for. The negative consequences of a strategy of retreat are self-evident. Adaptive plans usually meet somewhere in the middle. The following adaptation plan for Tybee Island has three facets: 1. Float the Marsh, 2. Retreat from the Beach, and 3. Fortify the ridge.

THREE FACETS –

FLOAT THE MARSH:

The first of the three elements that constitute the new adaptive plan for Tybee is to “Float the Marsh”. The landward marsh front is a critical component of the ecology and existence of Tybee Island. To preserve the marsh in conjunction with sea level rise, it must be allowed to creep. To facilitate the creeping of the marsh, four actions have been identified: 1. Eliminate infrastructure and armoring 2. Incentivize the TDR scheme 3. Phase the TDR scheme 4. Permit and plan for floating homes.

The first step in floating the marsh is to stop the investment in any form of stormwater infrastructure and shore stabilization. This makes sense because it saves money from being spent on infrastructures that are to be rendered obsolete and detrimental to the marsh, and it leaves room for more sustainable and affordable solutions to be implemented. The spirit of this action is to cease spending time, energy, and money on fighting sea level rise. This plan uses sea level rise itself as an incentive. This prohibition of infrastructure and armoring will render certain properties and structures more vulnerable to flood damage due to sea level rise. This susceptibility will be an incentive to follow through with a buyout option presented by this plan: Transfer Development Rights. This buyout option leads to two post-TDR alternatives, vacation or implementation of a new amphibious architecture.

The buyout option of Transfer Development Rights will allow those with homes in zones delineated by the plan to sell their development rights to a buyer with property in the receiving zone as delineated. This replaces the owner selling their home or property, which will be impossible at that point because of the impending risks associated with a rising sea level. Once the development rights are purchased and the owner receives compensation, the home, structures, pavements, and any sort of shore stabilization must be razed. This resolves the problem of being left with uninsurable property due to increased risk of flood damage. It allows the owner a “way out”. It enables the marsh to creep unimpeded by anthropogenic structures. The marsh will be able to creep landward with the rising sea. The alternative to vacating the property and releasing it to the state as land for conservation is to use the TDR funds to construct a new home according to certain guidelines and models. This post-TDR alternative of adopting and erecting a new flood proof amphibious architecture allows those who own property to retain a home or structure on it without the risk of flood damage or the inability to receive affordable flood insurance. The lack of a necessity for hard infrastructures and impermeable public rights of way, in conjunction with the low density pattern to be expected will allow for the marsh to creep with the rising sea level without damaging these homes. This buyout scheme and the steps to get there are vital to this plan's success.

RETREAT FROM BEACH:

Current development practices on Tybee coupled with projected sea level rise will lead to the disappearance of Tybee Beach. This coming disappearance can be mitigated and reversed with a developmental retreat from the beach. This retreat will be facilitated and made economically feasible by a phased TDR scheme similar to that of the marsh. The beach is the main economic driver for the island and its preservation for as long as possible is vital. As sea levels rise high tide marks migrate inland. On naturally formed beaches, Bruun's rule can be applied to expect a migration inland 50 to 100 times the magnitude of the distance raised by the sea level.[42] This rule is not so easily applicable to Tybee's Beach because it is artificially nourished on a frequency of every 7 years[43] producing an irregular slope. When running a GIS analysis of a SLR model, it can be noted that with +02'SLR, +03'SLR, +04'SRL, +05'SLR, +06'SLR, +07'SLR the inland creep of the shoreline is about 40', 40', 40', 80', and 250' respectively. This is caused by the beach having a steeper slope closer to the shoreline which is not as easily affected by a 1' rise in sea level until +06' SLR and above is reached. Above this +06' elevation mark, the slope is decreased drastically, and in

[42] Blakely, Edward J., and Armando Carbonell. *Resilient Coastal City Regions: Planning for Climate Change in the United States and Australia*.
[43] Wolff, Paul. "Tybee Island City Council Member Interview."

some areas of the beach, the shoreline moves in 250' or more with just one foot of sea level rise. This is shown in Figure 4.1 below.

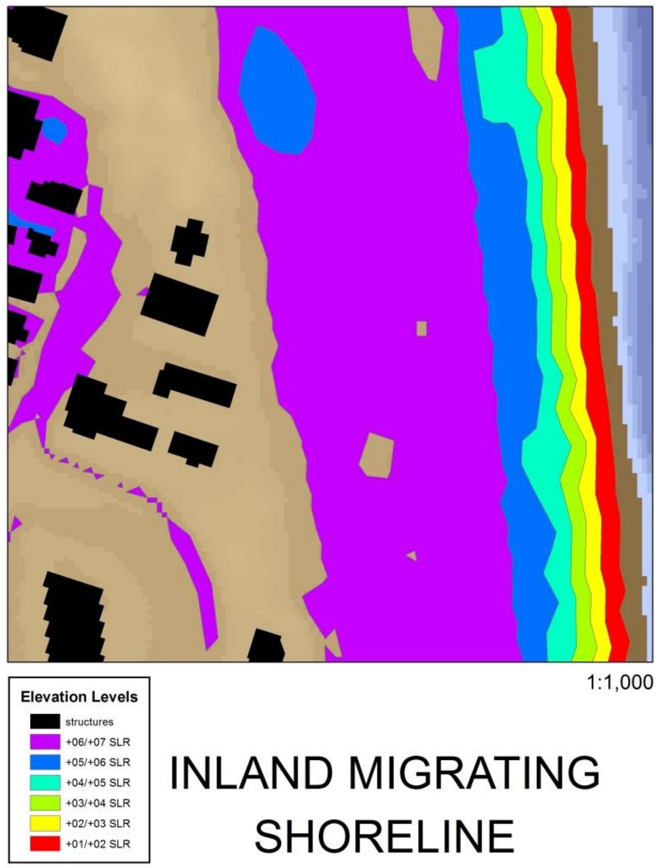


Figure 4.1 (Shoreline retreat in relation to SLR in 1' increments)

If the sea level does rise to +06' above what it is today as some models predict, by as early as 2080 some existing structures on Tybee will be less than 100' from the mean sea level shoreline. Homes and structures which are 450' from the shore line have a base flood elevation of +17' mandated by FEMA. The mandated base flood elevations by FEMA step back from each other about every 125' feet. If the shoreline were reduced to a mere 100' distance from a structure, not only would the measures taken to conform to FEMA standards become obsolete, but the structure may be found uninsurable when investigated by FEMA. This is because storm surge poses a greater threat to homes at a lower elevation closer to the shoreline, as do breaking waves and the hydrodynamic forces. Erosion, scour, wind loads, and other dynamic forces also begin to play a greater role as the shoreline moves closer. Not only will an inland migrating shoreline cause damage, risk, and value loss to properties and real estate, but the beach profile itself will be narrowed and lose square footage. This loss can be seen in Figure 4.2. Loss of beach square footage would be devastating for the economy of Tybee Island. The city's population swells from around 3,000 to around 30,000 due to its appeal as a beach vacation destination[44]. L The rate of SLR cannot be changed, so in order to maintain the beach square footage with SLR< the beach must be allowed to "migrate" inland in an approximately proportionate square footage it has lost. A scheme which allows inland migration of the beach would require a removal of buildings, structures, and infrastructures that are in the way. This abandonment of the beach shall be facilitated, phased, and incentivized in the same manner the abandonment of the marsh is: Transfer of Development Rights. This retreat, much like the marsh, will occur until a certain point. The seaward side of the ridge will be the location of the new beach front, and the retreat will occur until this point. Though this beach-retreat scheme will use TDR like the marsh scheme, the phasing will be a little different.

[44] Wolff, Paul. "Tybee Island City Council Member Interview."

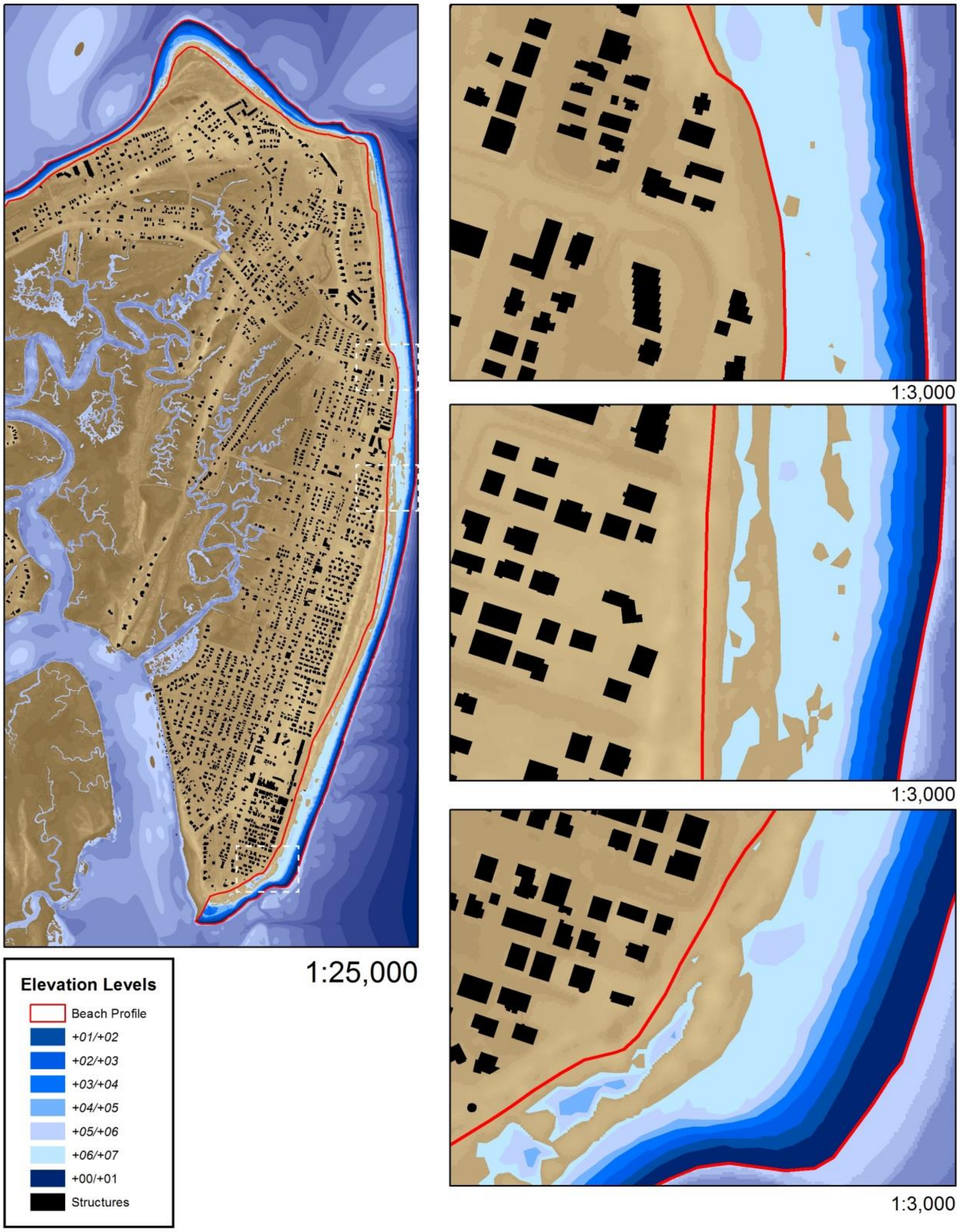


Figure 4.2 (Beach loss due to SLR levels)

approximately proportionate square footage it has lost. Inland migration of the beach would require a removal of buildings, structures, and infrastructures. This retreat from the beach shall be facilitated, phased, and incentivized thru a TDR scheme similar to the marsh's though the phasing will be different.

FORTIFY THE RIDGE –

Retreating from both the marsh and the beach on either side of the ridge is a move made to preserve the ecology and economy of Tybee for as long as possible. Retreat without a defined boundary would eventually lead to complete abandonment. The ridge serves as this boundary and it also serves as the receiving zone for the TDR schemes used on both sides of the island. Reinforcing and calling for densification ridge seems counter intuitive to the entire purpose of the retreat from the beach and marsh but it is not. The ridge is to be positioned at a point where if the sea were to rise any further the beach and the marsh would begin to disappear, regardless of any presence of human development. Placing the development and fortification here is not compromising any ecology that would not be comprised naturally regardless of development. The logic of this move is derived by evaluating Figure Series 4.3. It is clear from Figure 4.3a that when the sea level is +03', there is still plenty of room for the marsh and the beach to migrate inland. Looking at +06' in Figure 4.3b, there doesn't seem like there is much room left on the landward side (marsh) side of the island, while there still seems to be space on the seaward side. It is at this elevation (+06') that the developed ridge is to be overlaid on the still dry land and boundaries are inferred from this placement. The elevation of +06' was chosen was because this is the high end of the most regionally pertinent projections for SLR by the end of the century. Progression into +07' to +09' results in the dry and developable land is becoming more and more sparse. This can be seen in Figures 4.3c-4.3e. When looking at 4.3f and 4.3g, it is clear that at +09’ most of Tybee is underwater, and at +15’ over 98% of the island is underwater.   It is for this reason that the ridge is to be fortified and filled in to be +17’ above sea level. This ensures that if the day does come that the sea rises to +15’ what it is today, that Tybee will still be able to remain dry. This high ground will be the receiving zone of both TDR programs that flank it. Not only will this ridge allow the TDRs to operate properly but the economic loss due to the abandonment of property, structures, and population will be recuperated by the densification and relocation of these losses into the ridge. A new sort of Tybee Island will emerge with an evolved identity. A narrow spit of development just offshore exciting beachfront development and charming marsh-front living.

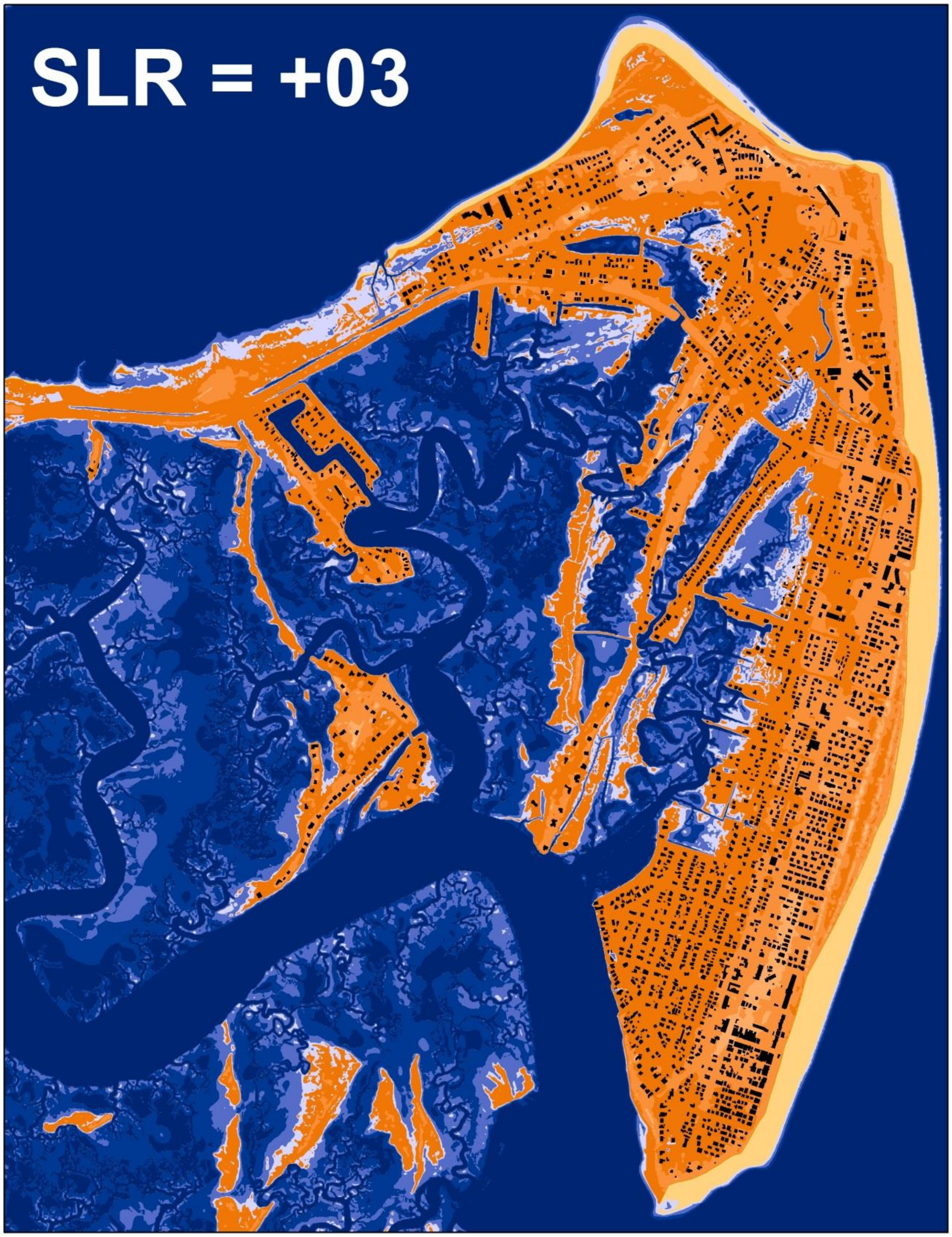


Figure 4.3a (Sea Level Rise Model: SLR=+03')

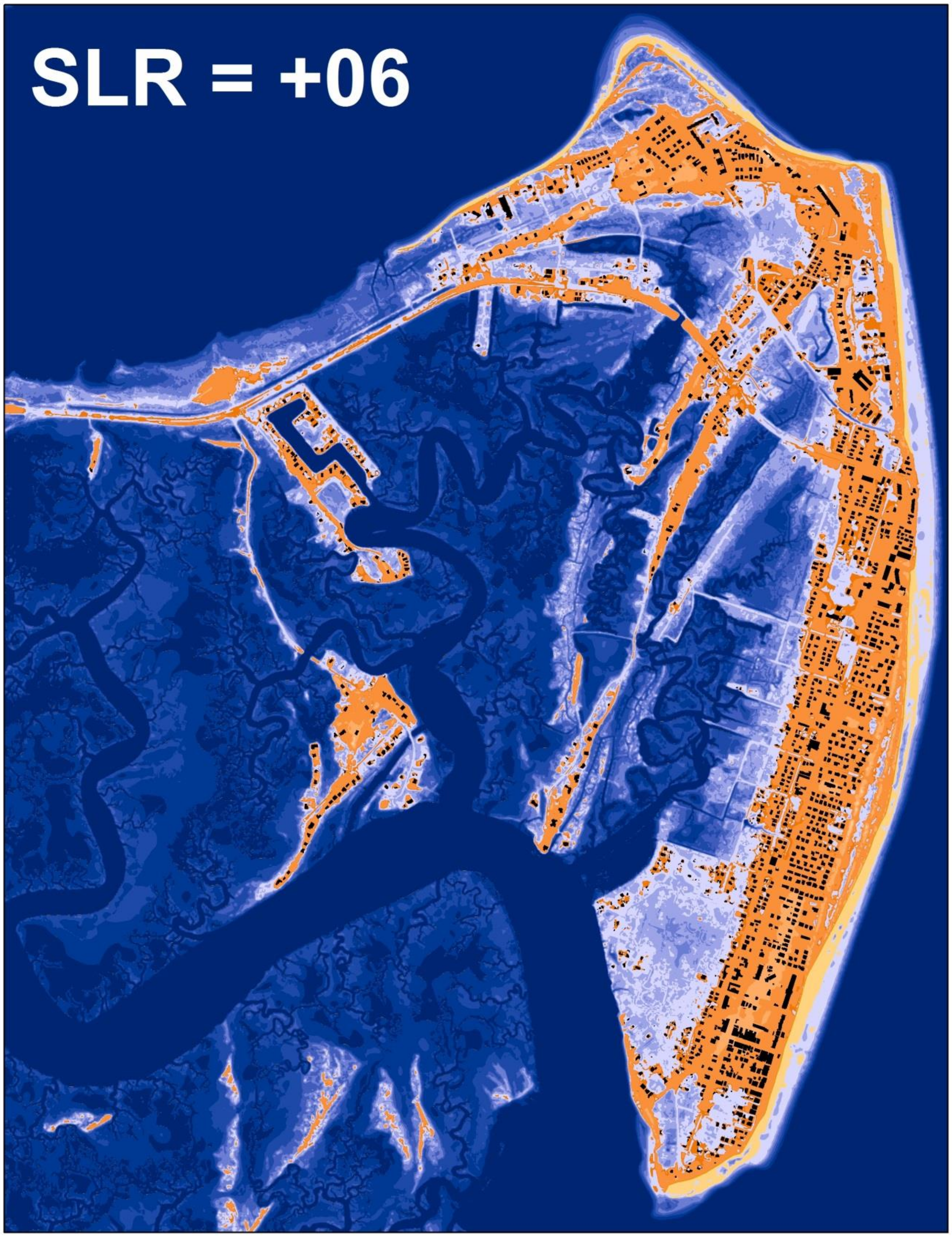


Figure 4.3b (Sea Level Rise Model: SLR=+06')

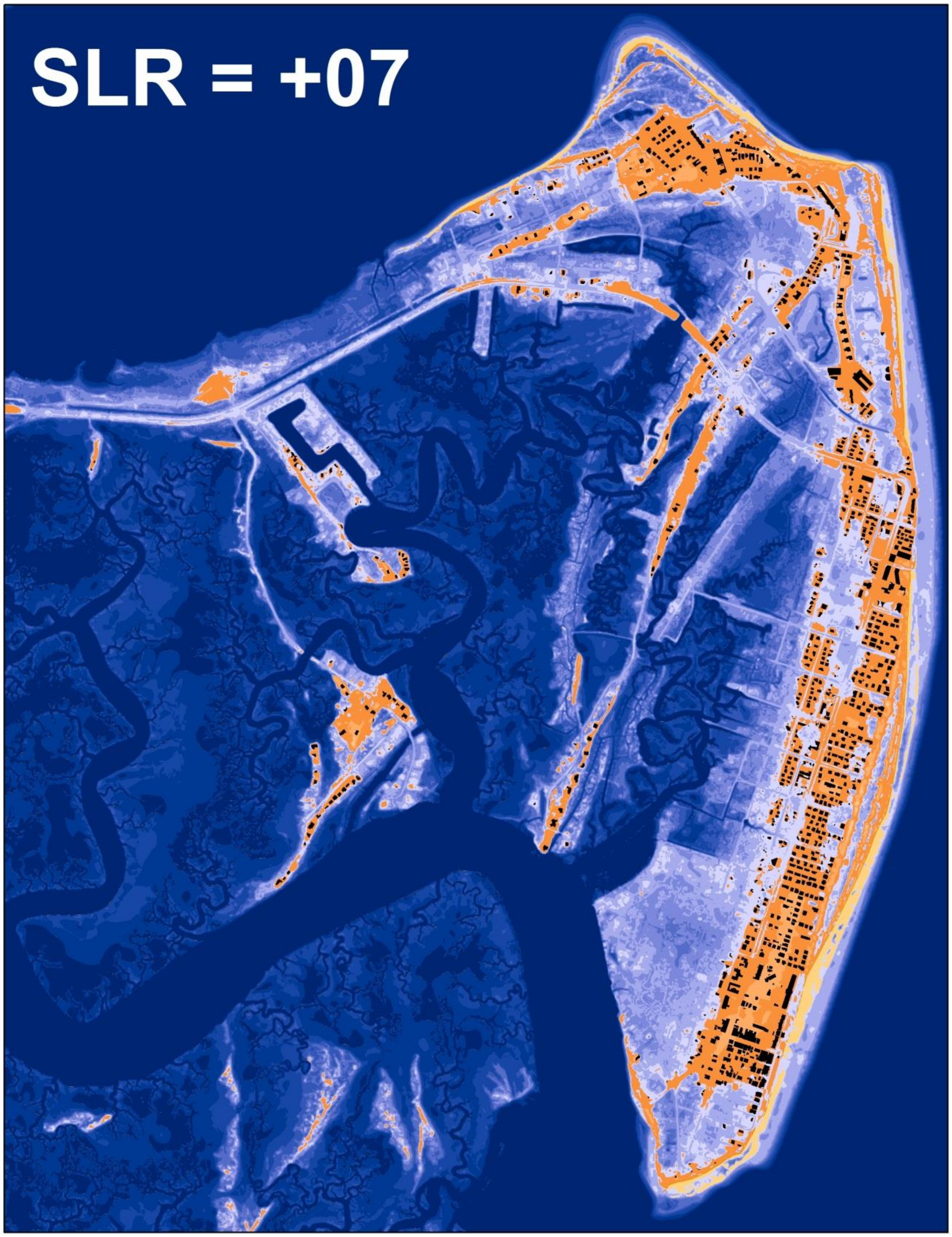


Figure 4.3c (Sea Level Rise Model: SLR=+07)

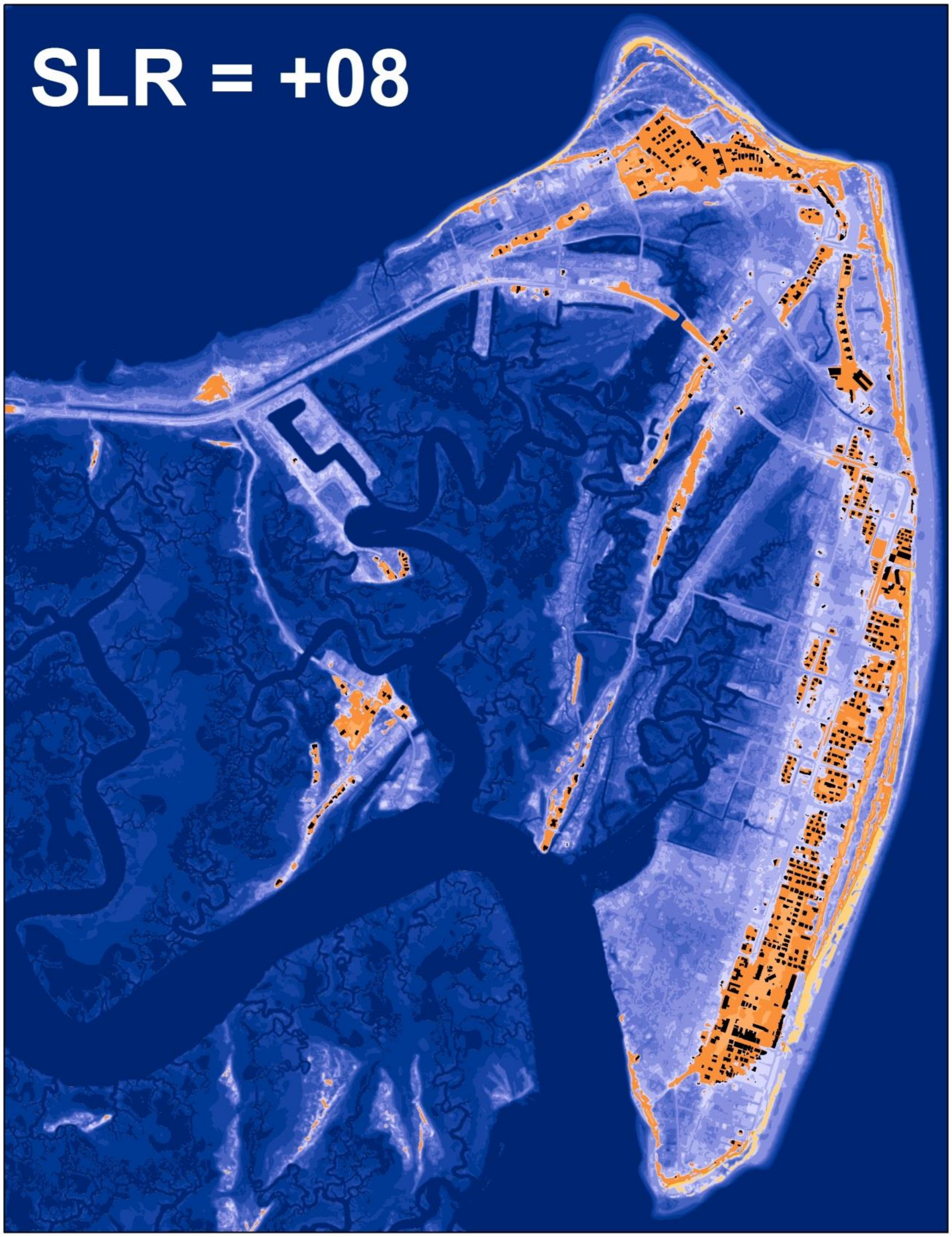


Figure 4.3d (Sea Level Rise Model: SLR=+08)

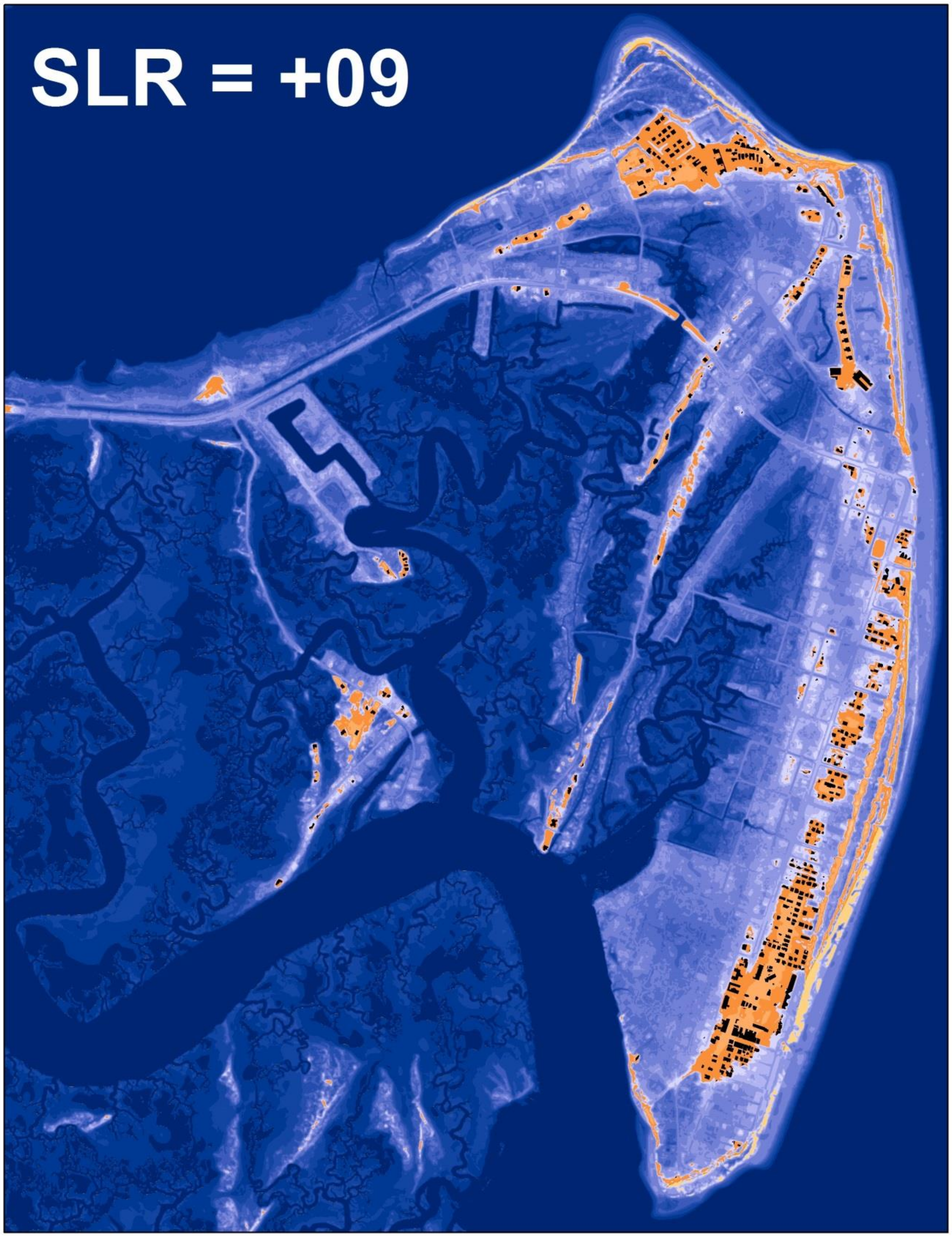


Figure 4.3e (Sea Level Rise Model: SLR=+09)

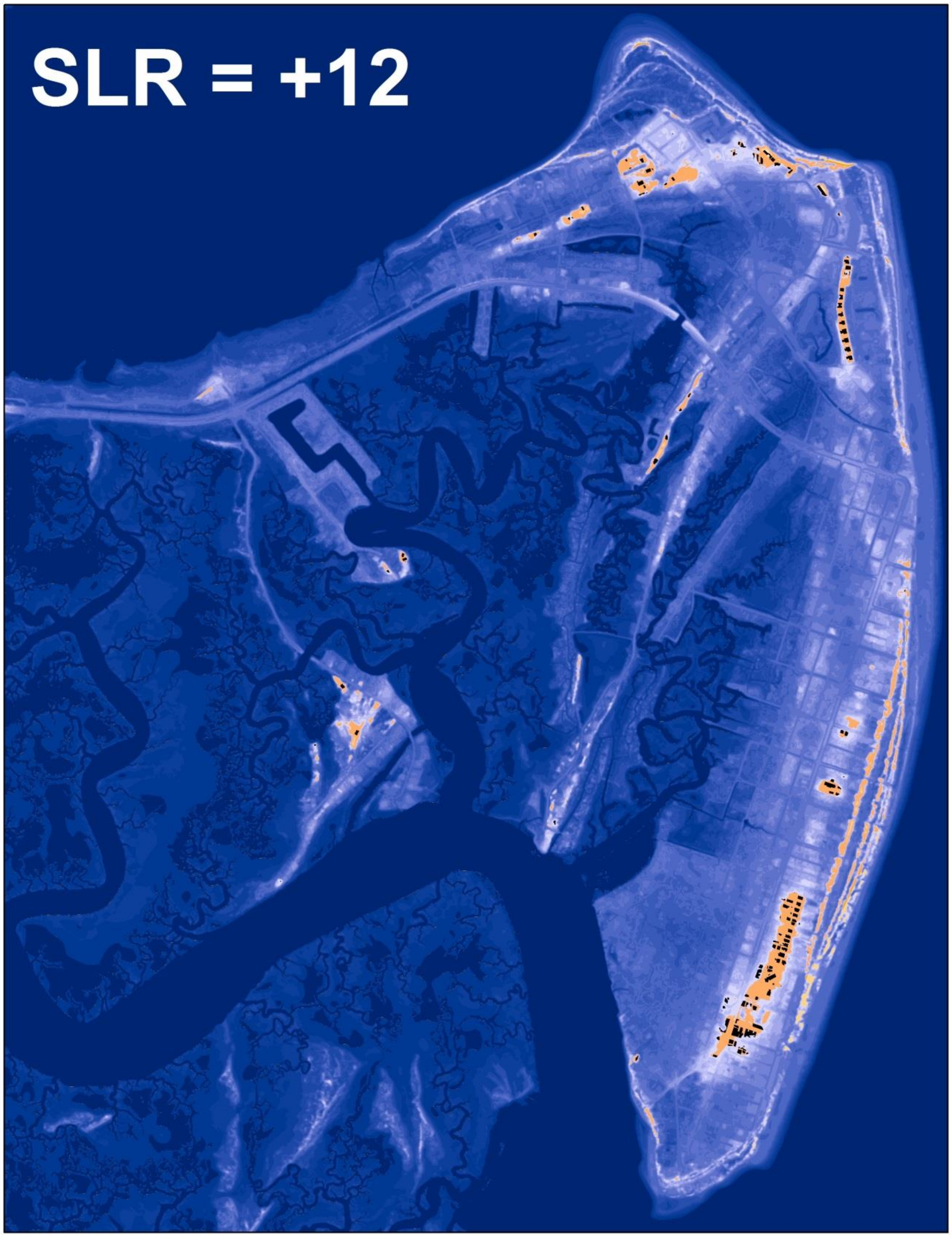


Figure 4.3f (Sea Level Rise Model: SLR=+12)

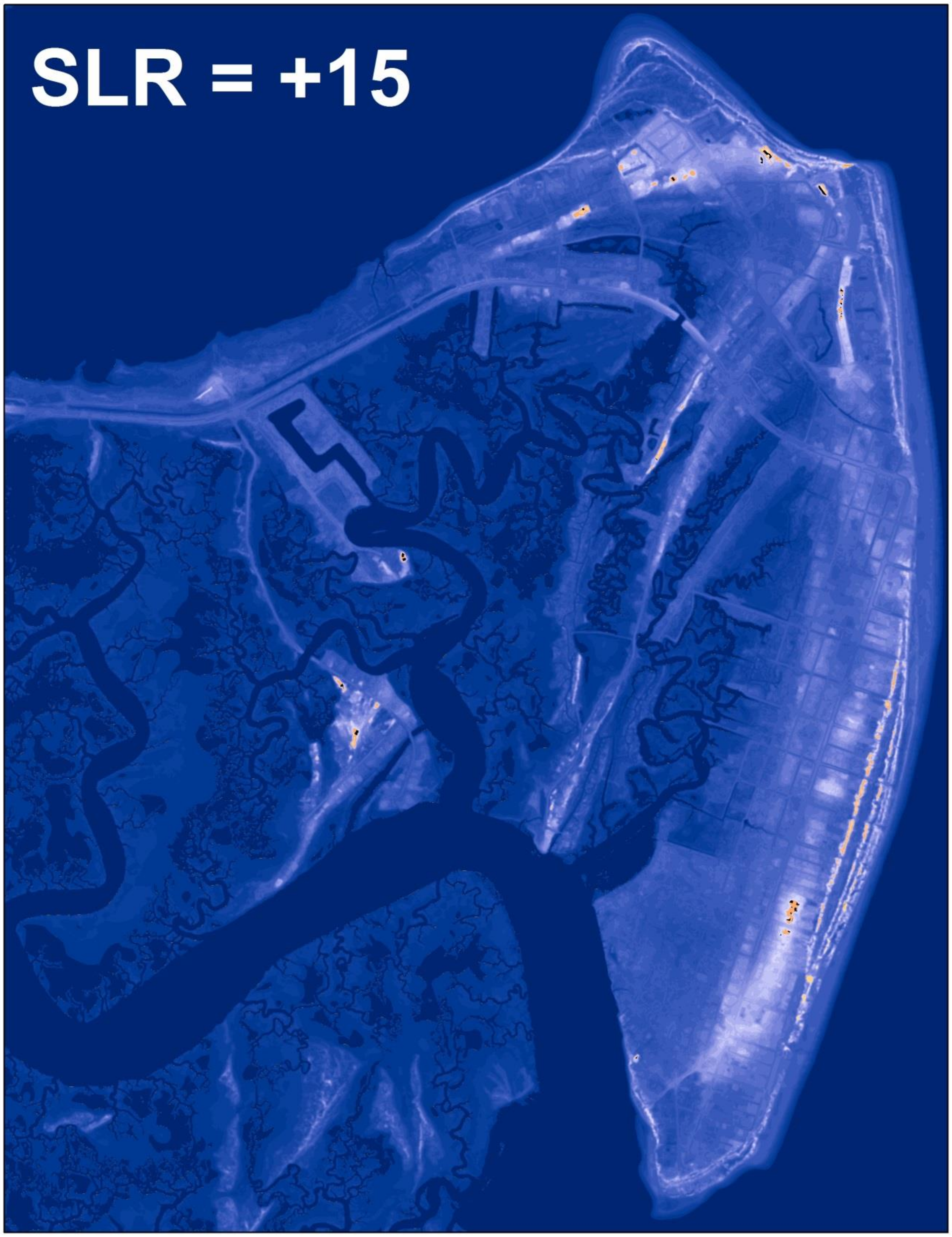


Figure 4.3g (Sea Level Rise Model: SLR=+15)

EFFECTUATION –

ELIMINATE STORMWATER INFRASTRUCTURE AND SHORE ARMORMENT-

Despite any ceasing of investment in retrofitted storm water infrastructure, storm water management still must be a priority to mitigate flooding. The storm water management system is not entirely reliant upon storm water pipes and discharge points. Figure 4.4 shows an existing ditch network that is tied into the storm water pipe network on the island. This ditch network is much cheaper to institute, contains no real demolition cost, and does not inhibit marsh creep. The ditch network is more prevalent in the low lying marsh areas already, which is a good thing. Despite this fact, there are still storm water pipes that run downhill to discharge point at very low lying elevations, as evident in Figure 4.5. It is these discharge points that have been focuses and recipients of retrofits. Instead of retrofitting storm sewer lines that run into low lying areas the lines should be removed and ditches instituted. Ditches are *designed* to be back flooded. This is a clear and sustainable solution. Instead of spending money to prevent back flooding in a system that is inevitably prone to it due to the site, allow it to happen! It can be noted that ditches are unsightly while storm sewers are invisible. This is a minor consideration that can be easily remedied with clever design work. Back flooding can be turned into a featured asset of a storm water system visibly in action, rather than a problem that needs to be forcibly restrained and hidden. An existing ditch on Tybee is shown in Figure 4.6. One example of a tentative ditch network solution is shown in Figure 4.7.

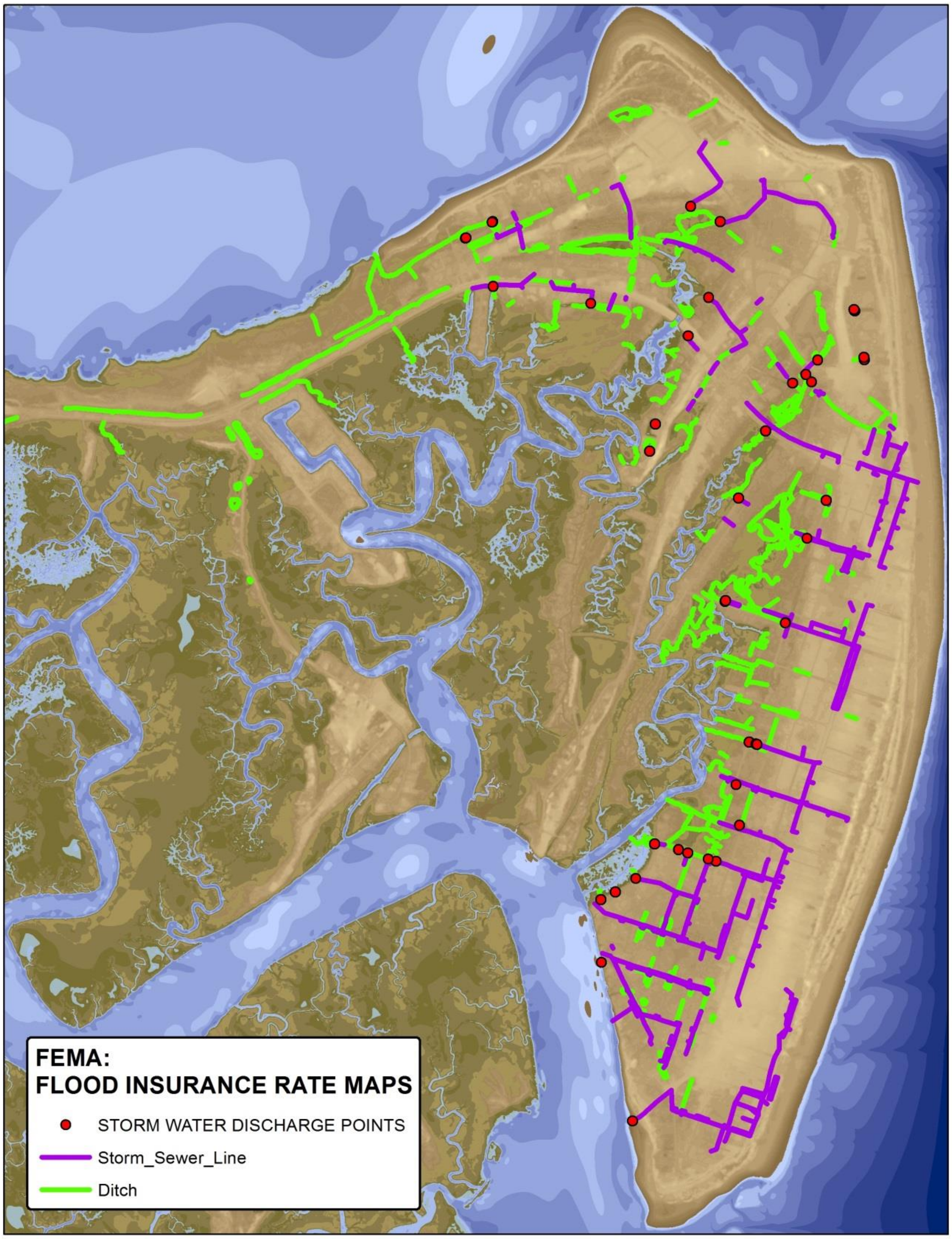


Figure 4.4 (Existing Storm Water Management Network on Tybee Island)

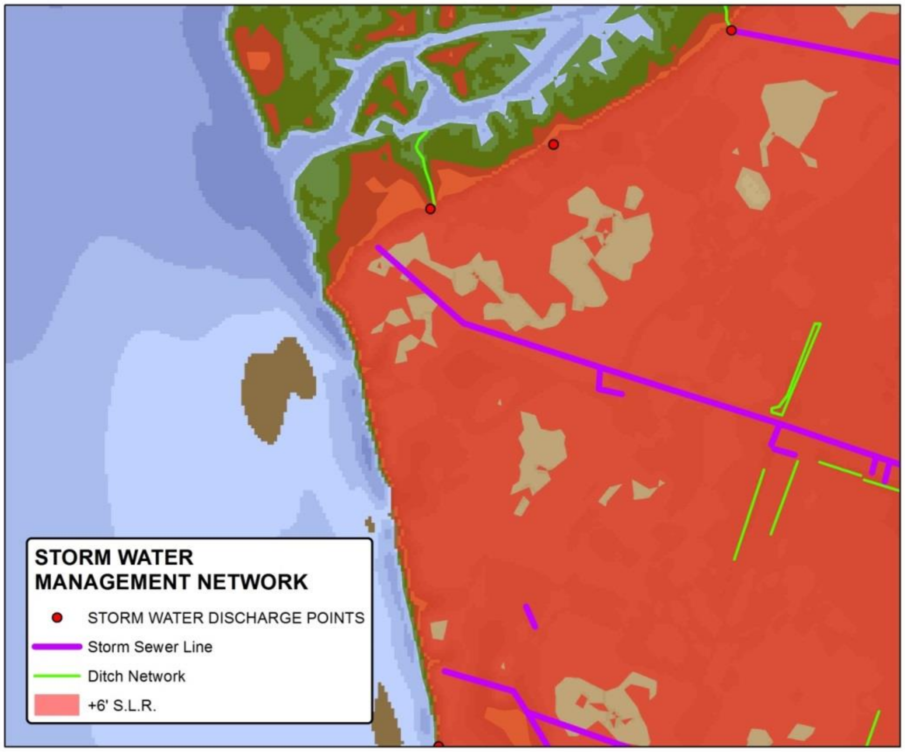


Figure 4.5 (Storm Sewer Lines Susceptible at +6 S.L.R.)

Figure 4.6 (Existing Ditch on Tybee Island)

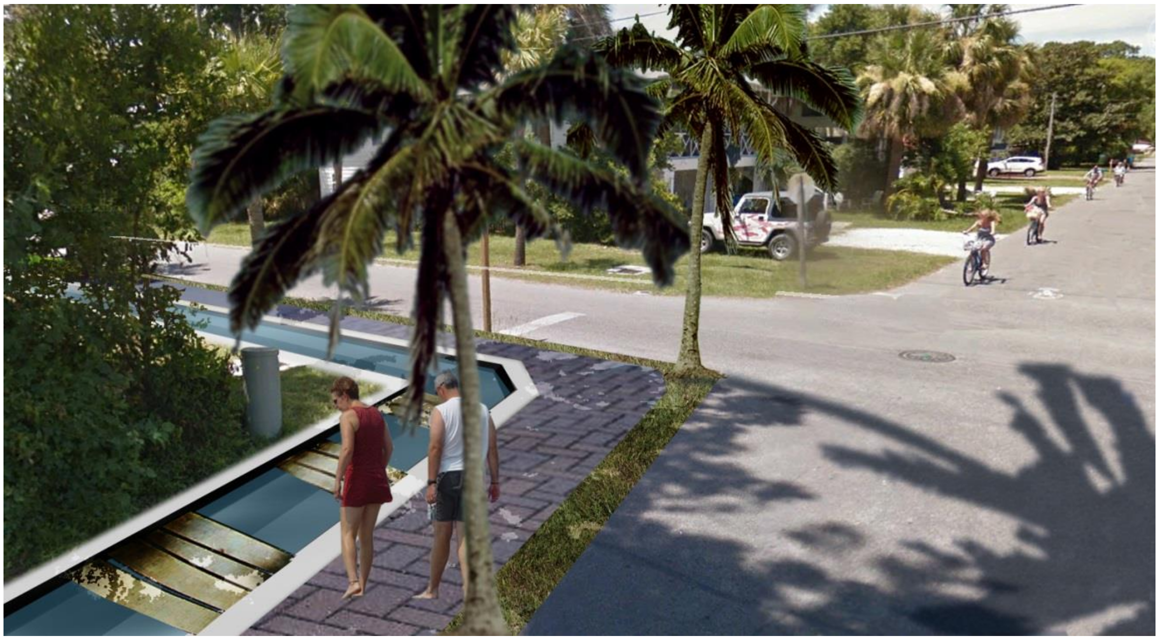


Figure 4.7 (Possible Beautification and Integration of Storm Water Ditch Network)

There exists several different instances and types of shore armoring on the landward shore of Tybee between the marsh and development. Figure 4.8 demonstrates the presence of shore armoring and its physical placement in relation to the site where the marsh would naturally creep if the sea level were to rise three feet. It is clear that the shore armoring is positioned to prevent the natural marsh creep. If this armoring is left in place, when the sea level rises high enough to perpetually inundate the marsh, it will die. This means that in order to not only allow for the marsh to creep, but to ensure its existence for as long as possible; these instances of hard shore armoring need to be razed (along with the structures it is protecting). This razing of the shore armament shall be phased along with the phasing of the removal of homes and structures.

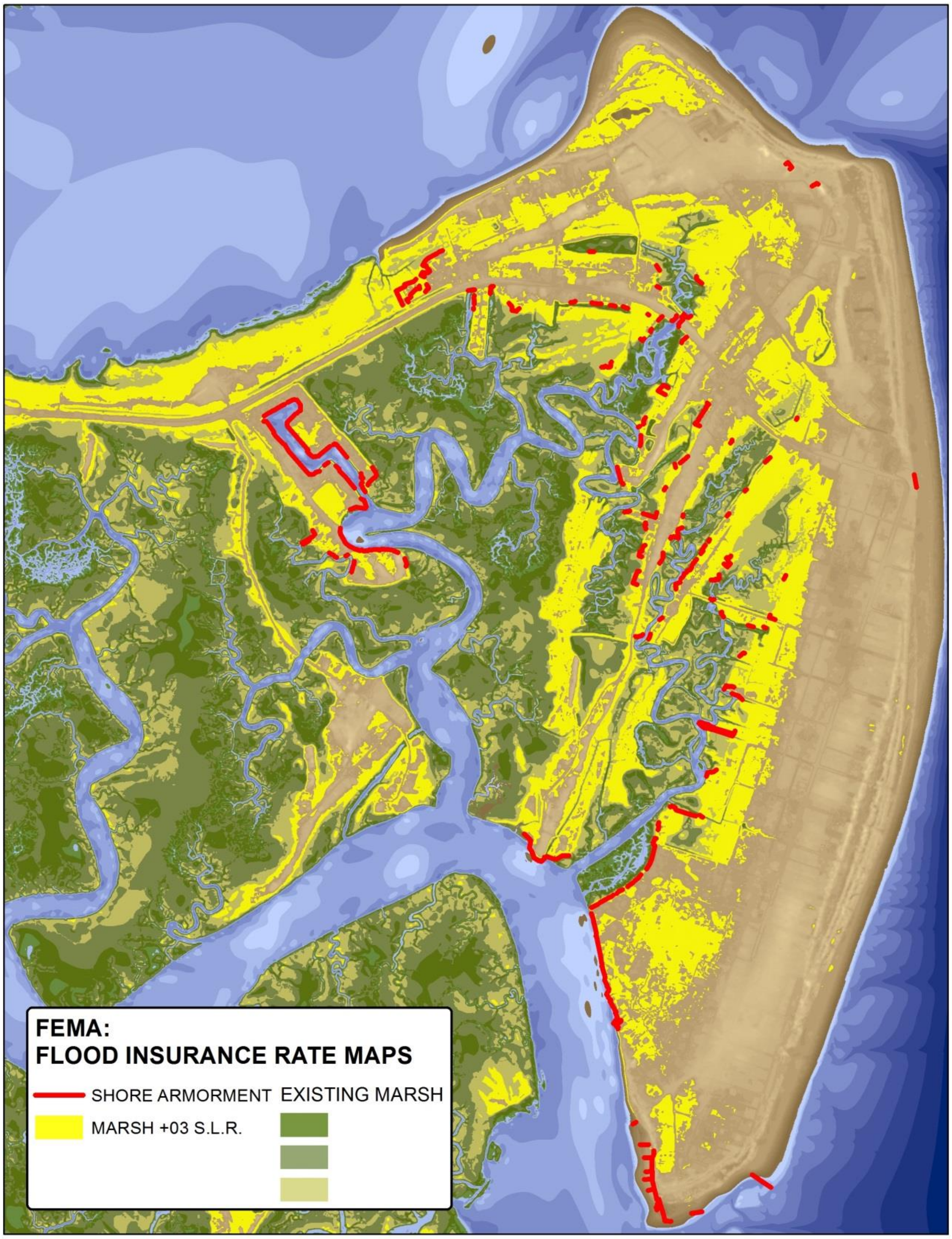


Figure 4.8 (Shore Armoring in Relation to Site of Natural Marsh Creep at +3' S.L.R.)

INCENTIVIZE TDR SCHEME –

It is not easy to convince homeowners that the best response to a currently non-existent threat is to abandon their home. The typical homeowner does not wish to a threat until it materializes and is real, but in the case of sea level rise, when the threat becomes visible it will be too late. There is an alternative to waiting for and suffering loss due to this rise in sea level, one of which is to sell the development rights to property owners or developers on the ridge. This option is providing a “way out” for home owners with dead-end property in the forthcoming marsh. They are exchanging the right to live and develop on their property for a fee much like a typical sale, though the person inheriting the real property rights do not get to exploit them on that land, but transfer them to property held elsewhere. This is known as a *Transfer Development Rights* scheme. A simple diagram illustrating how this works is shown in Figure 4.9.

Transfer of Development Rights (TDR) schemes are an innovative way to control development, and are to be adopted in this plan in order to make the abandonment of the marsh a plausible scenario. Though unlike typical TDR schemes where there is a designated sending zone (the site which the development rights will be removed from) and a designated receiving zone (the site in which the development rights will be utilized), this plan calls for a sending zone that migrates inland with the rising sea and

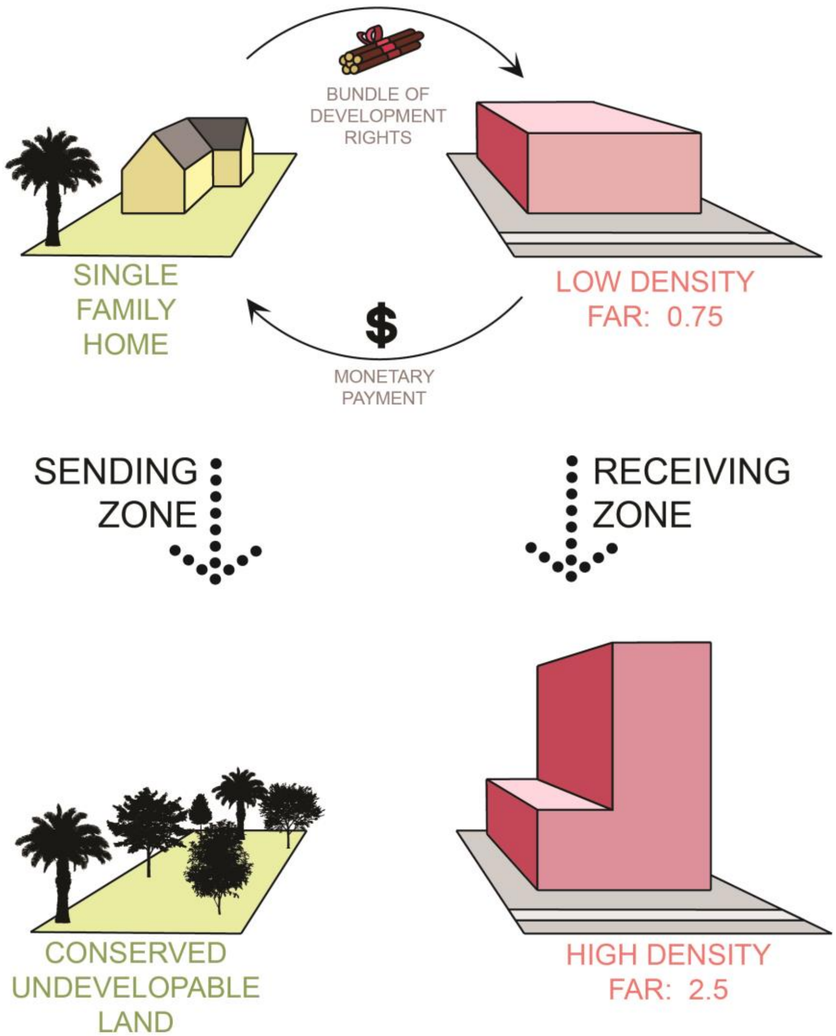


Figure 4.9 (Diagram Illustrating a "Transfer of Development Rights" Scheme)

creeping marsh. The receiving zone is to the be the high ground of Tybee Island in between the marsh and the beach, here after known as the ridge. The specifics of this TDR scheme need to be massaged further in order to ensure an efficient and successful plan. Specifics which will need to be addressed are things such as whether there will be a TDR Credit Bank (a body which stores development rights purchased despite a lack of land on which to implement them), what types of zoning, code, and density alterations will be allowed, and the exact procedure of closing sales and vacating properties. These specific issues pertaining to implementing a TDR scheme, along with many others, need to be addressed but are too complex for the topic of this thesis. What is important is that a scheme enabling a “buying out” of unsellable property is instituted and that it is phased properly so that the abandonment of the marsh is done so in a smart, logical, and orderly way with the fewest negative side effects possible.

PHASE TDR SCHEME –

In order to effectively coordinate and establish a transient sending zone associated with the TDR scheme, a phasing plan must be drawn and enforced. This phasing plan will be dictated by how quickly the sea level rises so that abandonment will occur at the required time to prepare and clear the land onto which the marsh will creep. The sending zone for the TDR scheme of Tybee Island will be transient, and will fall within a specific topographical range in relation to the sea level at that point in time. Currently, the extent of the marsh relates to the high tide mark, and is 2 feet above mean sea level. This is demonstrated in Figure 4.10. There are currently no homes on the marsh and it can be assumed that with every one foot in sea level rise (as long as it happens incrementally over time at a rate that does not exceed 3 cm per year) the marsh extent will raise one foot. This means that in preparation for a one foot rise in sea level, the space between the current marsh extent and the one foot mark above that extent needs to be cleared. This criterion can be used to establish the first and most pertinent sending zone.

Figure 4.10 (comparison showing elevations +0’-+2’ in comparison to satellite image of marsh)

The transient sending zone will be comprised of three concurrent topographical zones. Assuming that the two feet above the mean sea level is marshland, the transient sending zone will be ever shifting with the rising sea, though always begin at +2’ S.L.R. This means that currently, the sending zone begins within the +2’-+3’ contour, and continues to +3’-+4’ and +4’-+5’. Anything above five feet above mean sea level will be categorized as *Pre-TDR Eligible*, and will not be considered a capable sending zone until the sea rises an additional foot. As the sea level rises, these zones will rise with it. This stepping will not occur in increments of inches, but in increments of feet. When sometime in the near future, the sea level is registered as one foot above current day mean sea level, the +2’-+3’ zone will be considered *Post-TDR Eligible*. This is because that zone should be marsh territory at this point and inundation is most likely occurring. If it is made possible for owners to hold out until the marsh is at their door step and they are being constantly flooded, there will be no incentive to leave or remove their hard infrastructures before becoming an impediment marsh growth. Basically any land that begins as two feet above current mean sea level shall be known as *TDR Eligible*. This

TDR eligible land, also known as the sending zone, will have homes with three different possible minimum elevations. In order to incentivize pre-emptive transfers, a higher payout will be possible for those who have more recently become eligible than for those who have put off transferring development rights. This, while enabling a homeowner to possibly earn more through transferring development early, will ensure that the development rights closest to the marsh will be purchased first due to their low price. This process and the different TDR eligibilities are demonstrated in Figure 4.11.

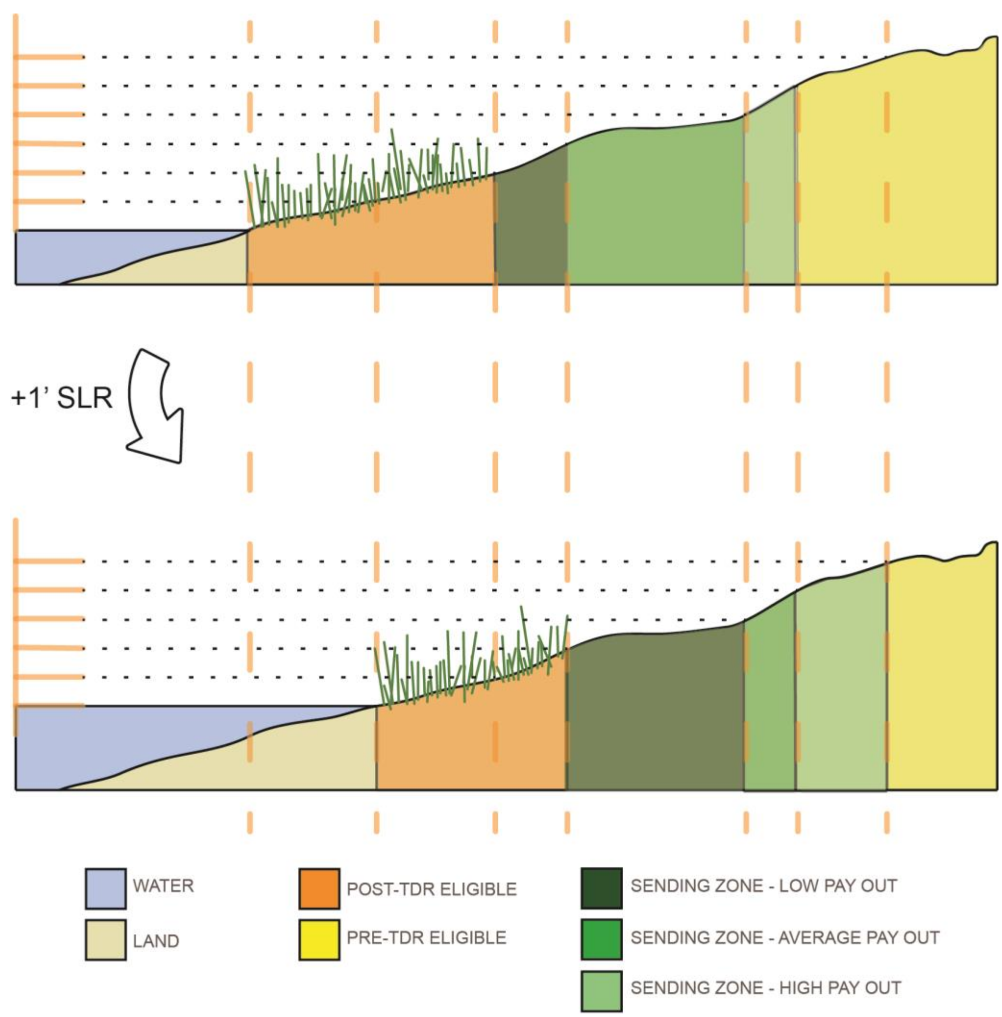


Figure 4.11 (TDR eligibilities and Sending Zone Migration)

It should be noted that unlike typical phasing plans, this phasing plan for the abandonment of the marsh is not contingent upon time. Time, in this scenario, is elastic. The sea could rise one foot in 10 years, or it could take 80 years, or it could never happen at all. The point is that there is a plan of action for when and if it does occur. That being said, the phasing for the marsh is demonstrated in Figure Series 4.12 below. The phasing for the implementation of the TDR scheme goes up to +6' SLR. This is due to the placement of the fortified boundary of the ridge. By the time the sea is six feet above what it is today, there will be very little marshland left and no land left to abandon. The Transfer of Development Rights Scheme is a way out for those who are facing depreciation of their property and homes. Once having transferred development rights, there are to possible scenarios to follow: to vacate the property releasing it to the state for conservation or to use the funds to build a new type of autonomous and amphibious architecture that adheres to the framework and guidelines to be established. This new architecture will be truly amphibious, able to be built and lived upon on land just as one would in any typical house on Tybee. This new type of housing will also be completely flood proof and will be able to actually float in water. Not only will is stand storm surge and high tides, but it will function and operate as well as any terrestrial house even when located in 10 feet of water.

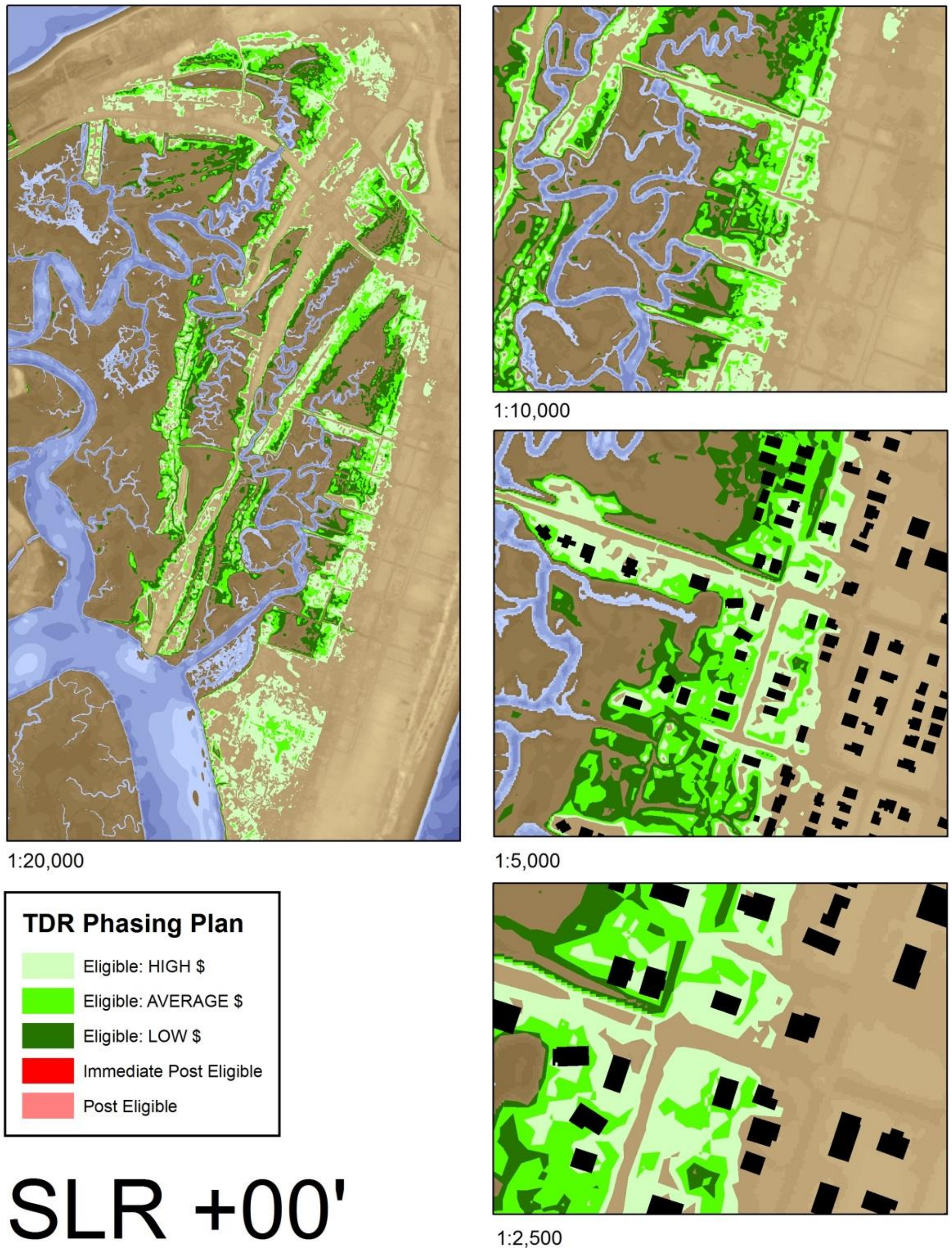


Figure 4.12a (Sending Zone Phasing)

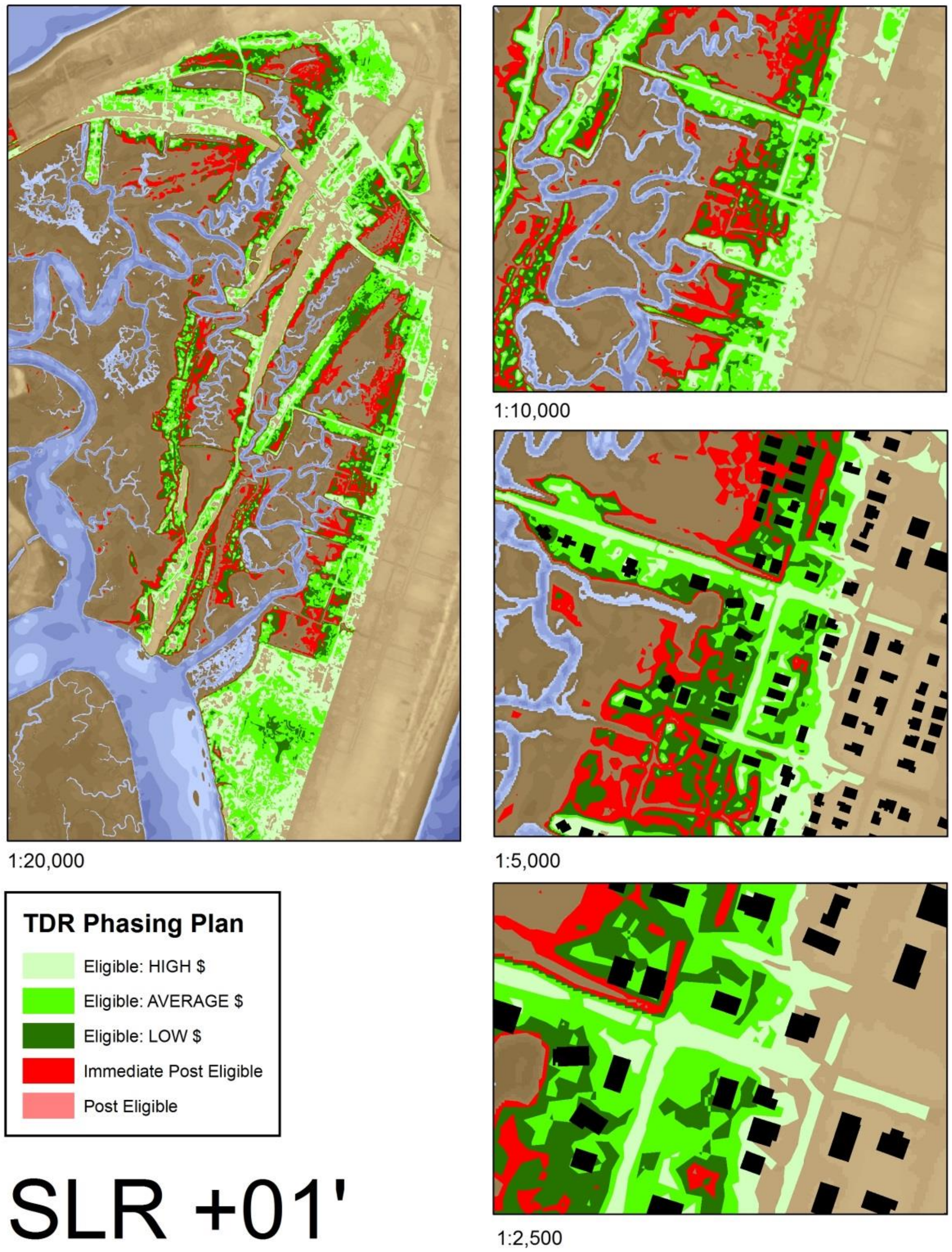


Figure 4.12b (Sending Zone Phasing)

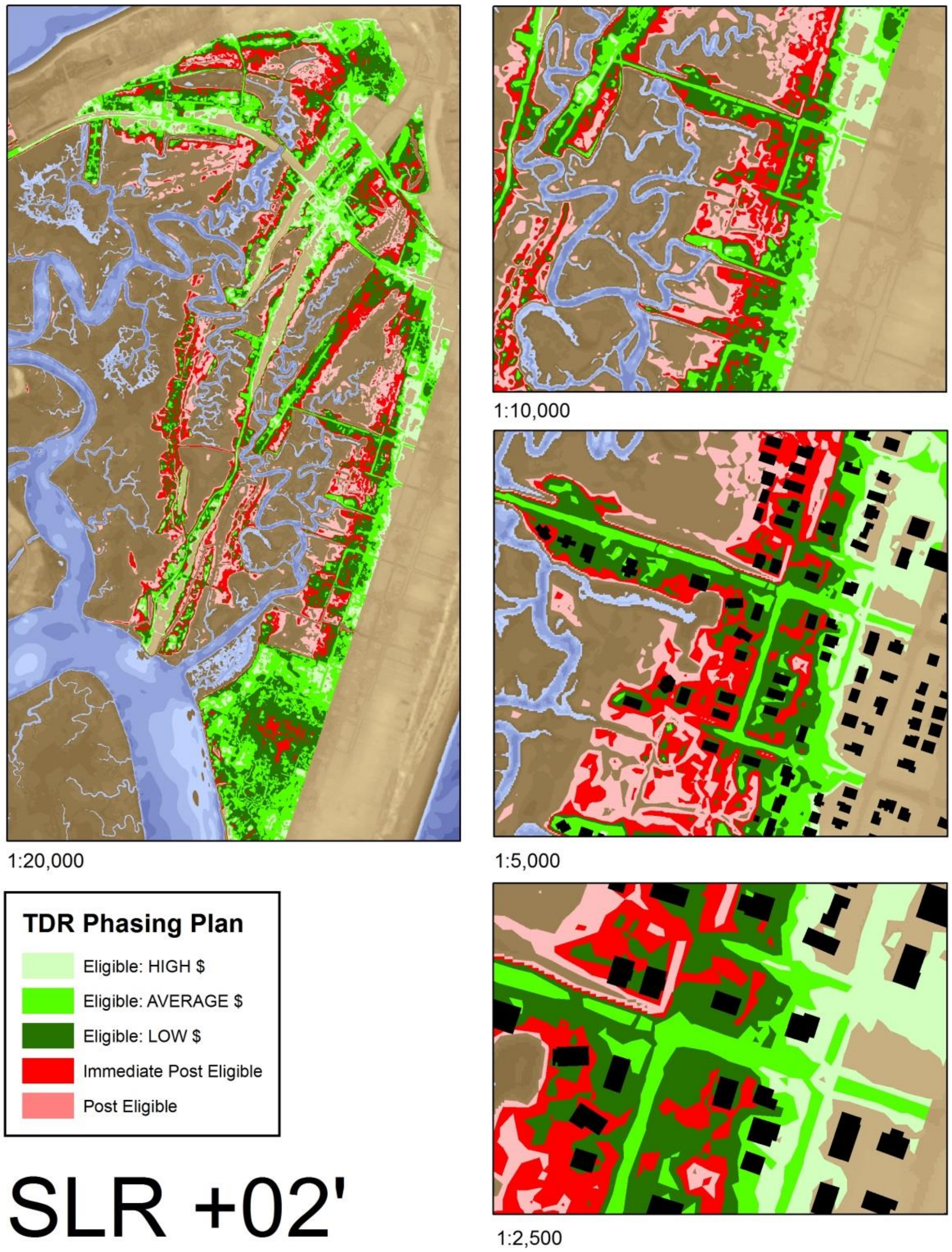


Figure 4.12c (Sending Zone Phasing)

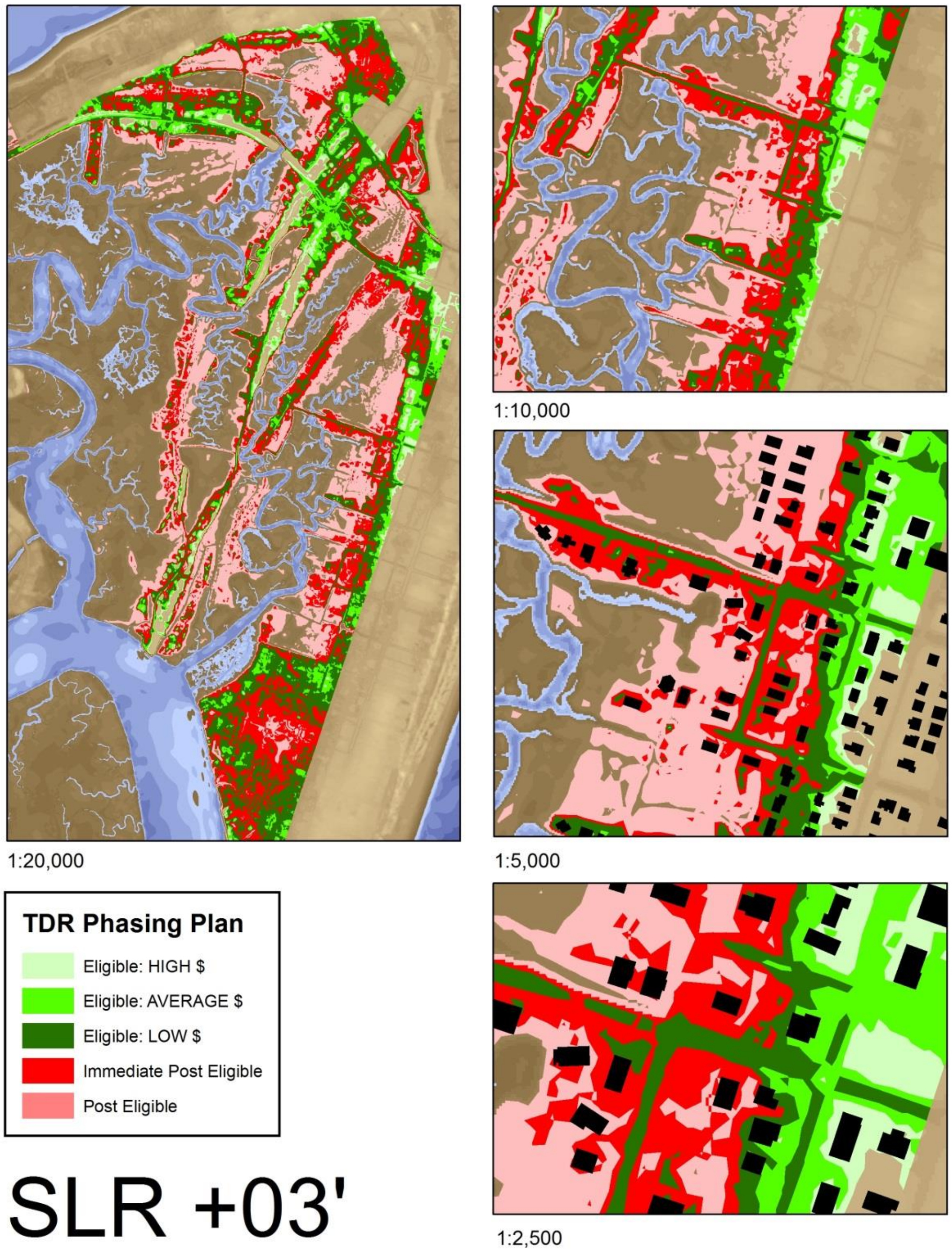


Figure 4.12d (Sending Zone Phasing)

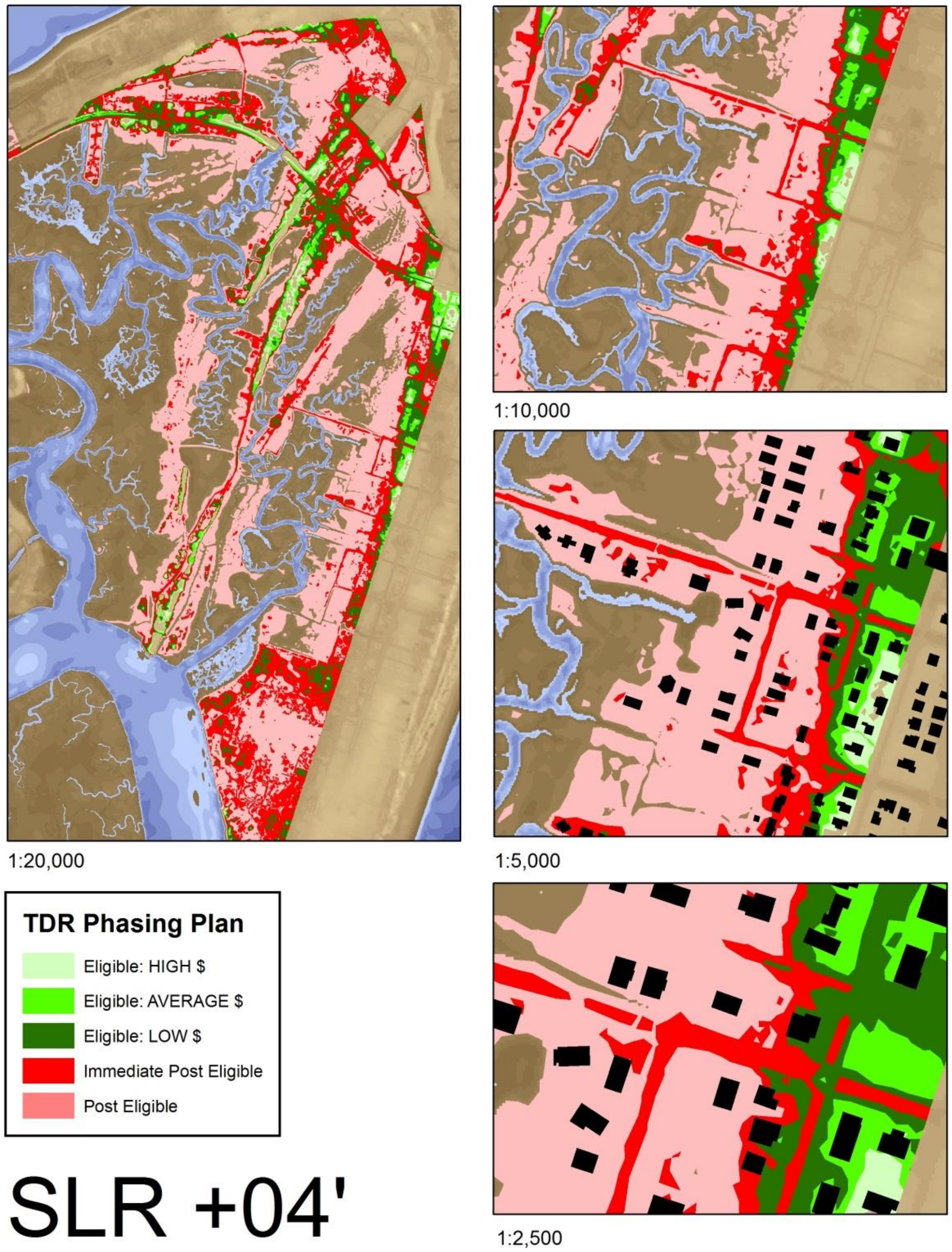


Figure 4.12e (Sending Zone Phasing)

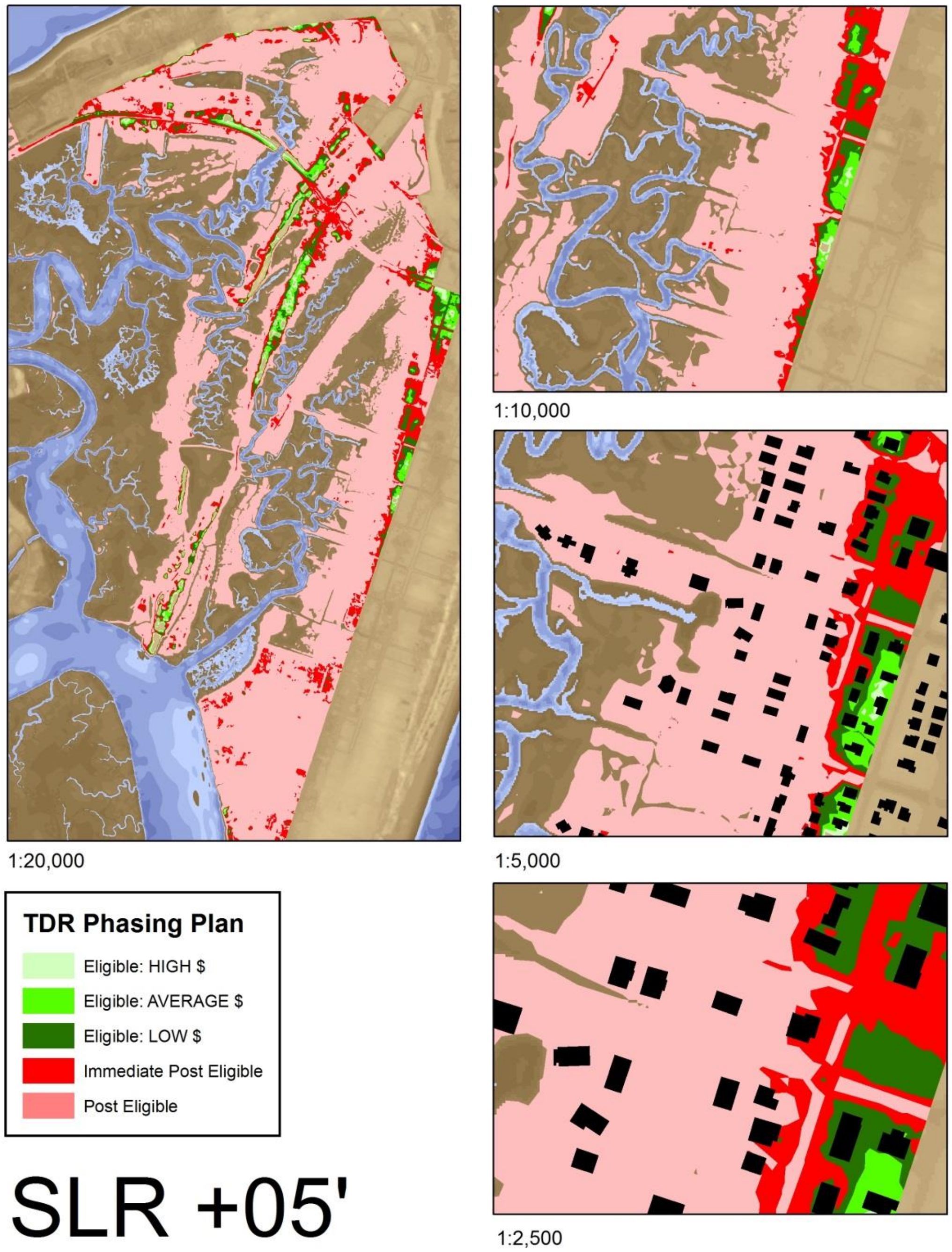


Figure 4.12f (Sending Zone Phasing)

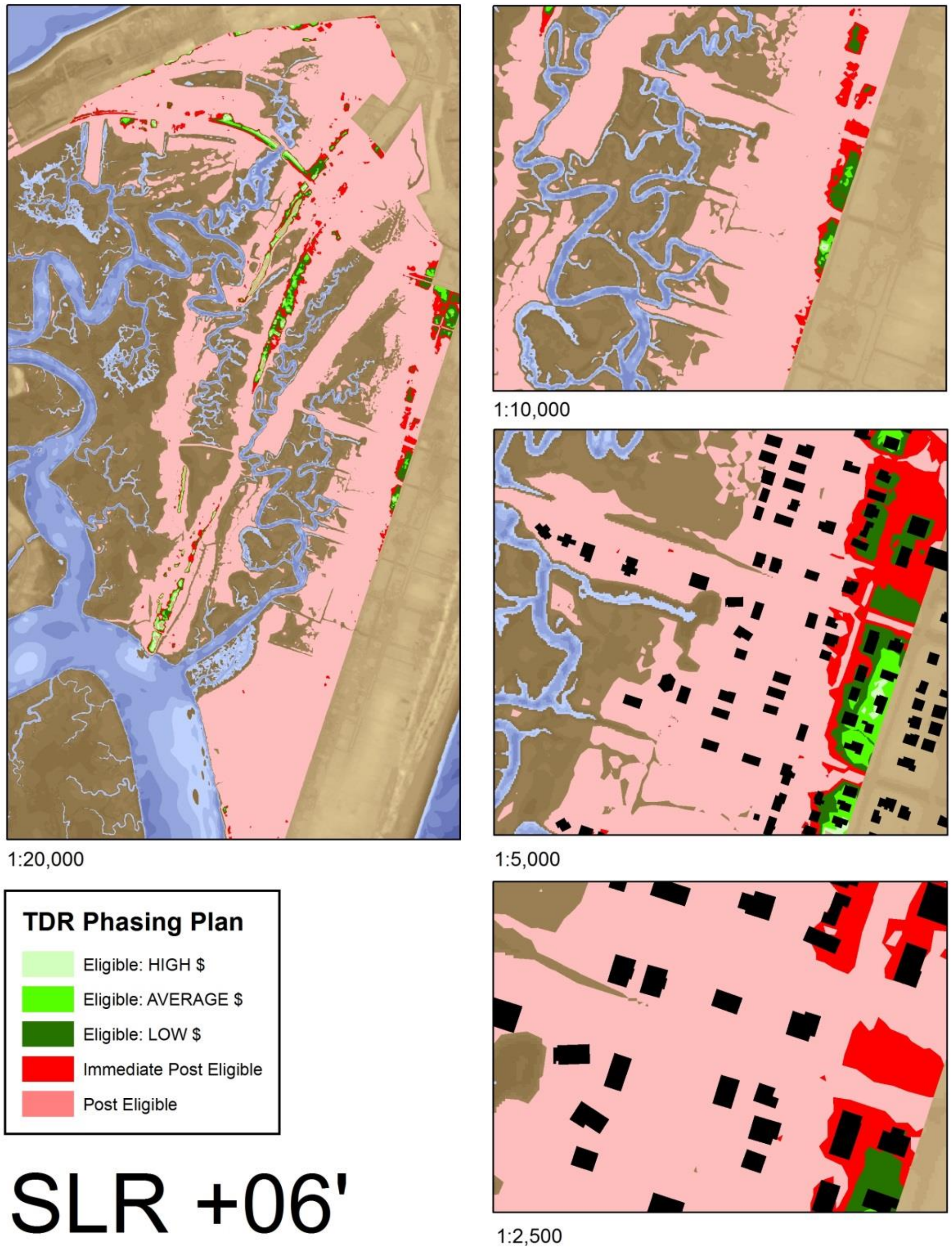


Figure 4.12g (Sending Zone Phasing)

PERMIT AND PLAN FOR FLOATING HOMES –

For those who, after having transferred development rights and razed all structures on their previously owned property, wish to maintain a life on Tybee and invest in a home that will not become obsolete or vulnerable in the coming decades, a new model of floating home development may be constructed. These floating homes are able to be built and lived in on land, while also being able to withstand slight temporal inundation associated with tidal fluctuations. They are able to do this because they are completely autonomous from the site. These homes do not have a terrestrial foundation but a concrete caisson made of lightweight concrete that is connected to the load bearing walls, and it serves as a built in foundation on which the house rests. These homes are ideal because, while able to operate with the standard types of infrastructures presently utilized by homes in the marsh, they are designed to be able to operate with an entirely different infrastructure system as well. the current infrastructures that support single family detached housing units on Tybee Island vary, but mainly consist of water, electricity, sewer, and access infrastructure such as paved surface streets. These infrastructures are tied to the land upon/in which they exist, and any introduction of perpetual or daily inundation would render them obsolete/dysfunctional. Even if one were able to flood proof a house so that it would withstand daily inundation up to 1' at high tide, the infrastructures supporting the operation of this home would fail. Typical residential sewer and water lines are not designed to operate under constant inundation by salt water. It is obvious to state that one foot of water would render surface streets unusable. Power lines may not be able to withstand this type of inundation either. This is not simply the home that needs to be designed to withstand flooding or life on water, but it is the infrastructures that support homes as well.

One major consideration that needs further exploration is the public right of way to access these amphibious homes. At some point these home will be inundated daily at high tide. It is a simple solution to access a floating house in 10 feet of water: boats, jetties, and other well developed systems. The real question is how to access a home in 10 inches of water? There must be some form of public right of way to replace the streets. Some sort of flexible jetty/boardwalk/walkway system must be adopted. There are similar networks at work in floating communities around the world, and they can be looked to as a precedent. When should this the transition to the new infrastructure system be implemented? The most logical answer to finding the right transition period is when these amphibious homes are considered to be in a “Immediate Post Eligible Sending Zone”. Once a home is considered post eligible, it means it is in marsh territory, meaning that it is at direct risk of flooding. Figure Series 5.9 can be referenced to see the progression of immediate post-eligible zones versus zones which have been post eligible for a while. It is in these immediate post-eligible zones that infrastructures and rights of way will be constructed and implement to ensure proper functioning of the amphibious architecture adopted there. The same phasing process that dictates this infrastructure effectuation and abandonment of the marsh is used on the seaward side of the island, in retreating from the beach.

PHASE RETREAT FROM BEACH –

The TDR program to be used in the retreat from the beach will use the same concept of allowing those with impending losses impossible to recuperate through a real estate sale to have a way out, though the phasing and definition of the sending zone will be different. One main difference of this scheme is that the retreat is not being executed in order to ensure the survival of the beach through a natural migratory. The beach does not necessarily need time to creep. It can be artificially recreated or “nourished” at any point in time. It is because of this, and because of the fact that these beach front buildings are vital parts of the economy that phasing of the sending zone will occur within one topographical zone at a time. There will not be a high, low, and average sending zone incentivizing a quick sale of development rights. The classifications of pre-eligible, post-eligible, and eligible are still pertinent. Another difference in this phasing is that it is not going to be physically delineated by topographical lines and boundaries. The transition from one sending zone to the next will be dictated and paced as the sea level rises in one foot increments, but the zone delineation will actually be a buffer zone retreating inland from the existing shoreline. This can be seen in 4.13. This buffer zone which delineates the sending zone relates in magnitude to the predicted amount of beach profile loss. For instance, the shoreline is predicted to move inland 40' with a rise from +01 SLR to +02 SLR.   For this reason, the sending zone steps back another 40' from the previous end line of the sending zone, and now all the homes and structures within that 40' buffer are TDR eligible. It is very clear to see that a 250' predicted shoreline retreat marks a 250' wide sending zone for the +04 SLR to +05 SLR period. It can be noted that the initial sending zone for the +00 SLR to +01 SLR period is 80', which does not relate to a 80' inland shore migrating but doubles the predicted 40' migration in order for the phasing of the retreat from the beach to get a head start. This enables the sending zone of 250' when the sea level is +04/+05 relate to the predicted inland shore migration of 250' accompanying the sea level rise between +06/+07. It may also be noted that the sending zone seems irregular at the +05 SLR and up mark. This is because at this point, the sending zone is very close to the future edge of the ridge.

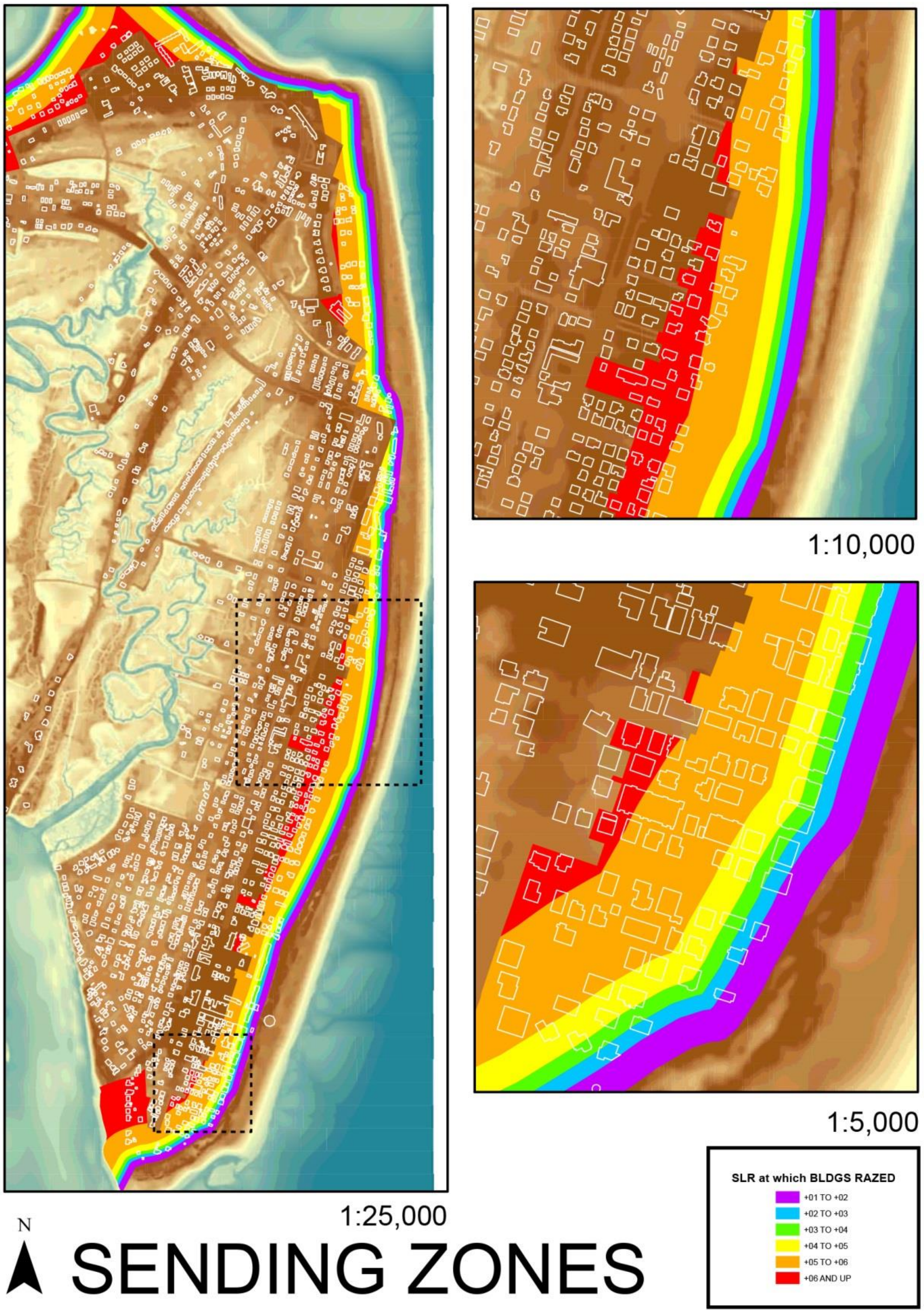


Figure 4.13 (Beach Retreat Sending Zones)

When the sea level has risen above +06', the retreat from the beach will have been completed. All homes and structures within the sending zones will have been razed, regardless of whether the owner took advantage of the TDR scheme. All that is represented as a sending zone in Figure 4.13 will be future beach.

CONTINUE TO RENOURISH –

The current nourishment schedule for Tybee beach is a necessity for its existence and needs to be maintained. The nourishment cycle will need to be examined an altered as well in order to deal with any conditions accompanying sea level rise which render the current frequencies or volumes insufficient. The retreat from the beach can be considered a recalibration of the nourishment cycle. Retreating from, razing buildings in, and abandoning the beach is not a method that alters the volume or capacity of the nourishment cycle, but one that alters the field upon which the nourishment cycle is enacted. It will increase the depth of the area to be nourished in response the decreasing of this depth by sea level rise. It is even a possibility that once the sea level rise hits six feet above what it is today, the shallower grade of the beach will make nourishment unnecessary, allowing the beach to sustain itself without the need for human intervention. Dune migration may begin to occur naturally, though this may need to be facilitated by human intervention. This inland creep of the beach and the dune field will help preserve the backbone of Tybee's economy, and the new beach will be defined by a new beach front and a new ridge of development.

ESTABLISH BOUNDARIES -

A delineation of where the retreat stops and the ridge fortification and densification begin is critical. These boundaries that define the ridge need to be situated in a thoughtful and careful manner. They need to be placed so that the remaining areas to densify are not too narrow for development and not so wide that they kill the marsh prematurely or detract from the beach. The boundaries need to be at a high enough topography to ensure time enough to phase the retreats comfortably, and situated so that the ridge can be elevated to a safe height assuming the worst conditions of SLR in the coming century. Using the +06' SLR model as a guide to what areas, land, blocks, and parcels should be salvaged identifies a relatively high ridge running along a N-S axis on the southern part of the Island. There is high ground in the northern part of the island as well, and though it is not so connected or linear this fragmentation translates into the boundaries delineated for the ridge as well. The working process of formally laying out the high-ground is visible in Figure 4.14, which then translates into a final boundary scheme in Figure 4.15. This idea and diagrammatic intent was overlayed onto existing parcels of Tybee. In order to decrease the amount of takings or re-subdivision, the boundaries of the ridge were delineated so as to keep most parcels at the edge intact.

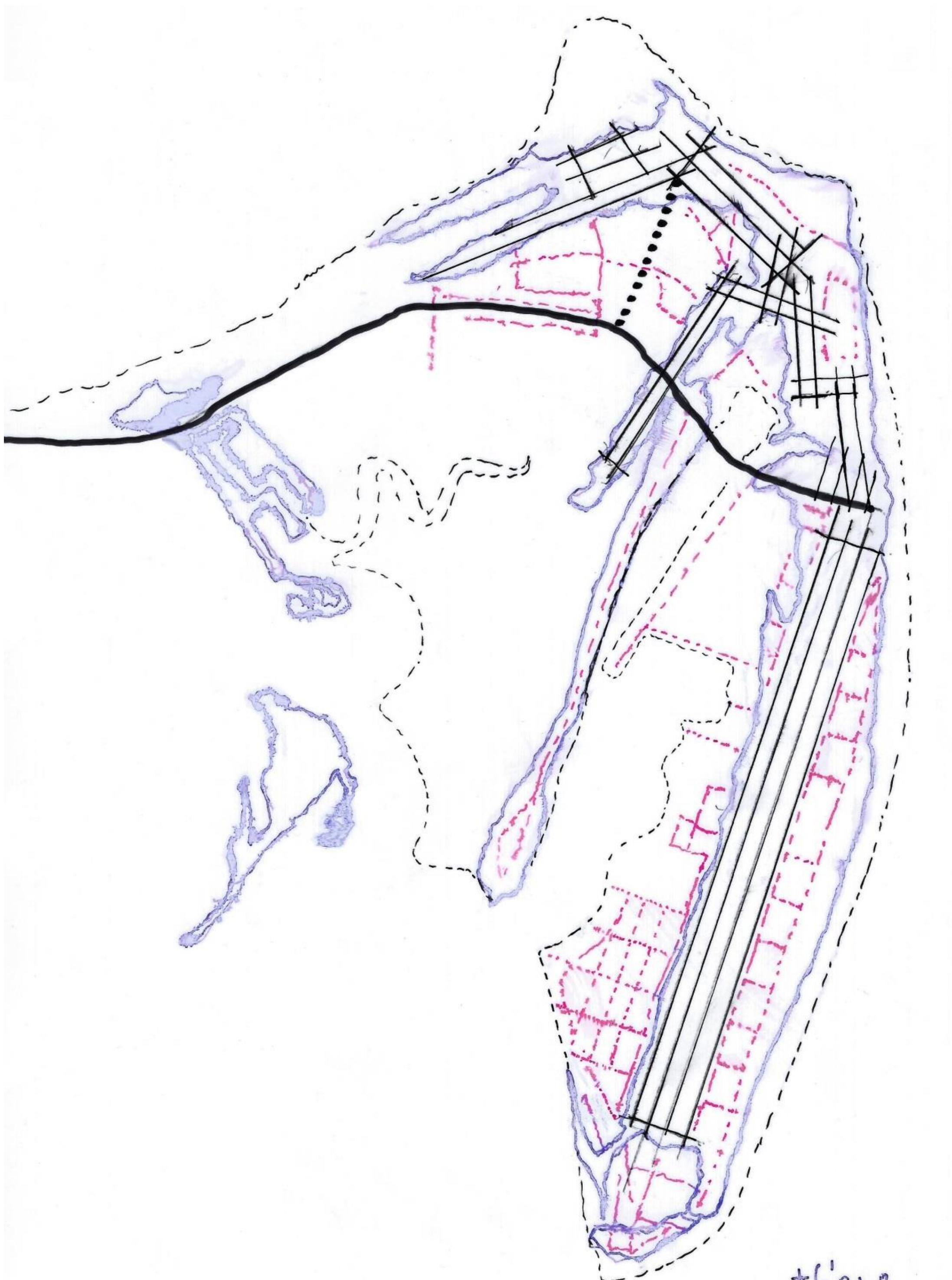


Figure 4.14 (Boundary delineation working scheme)

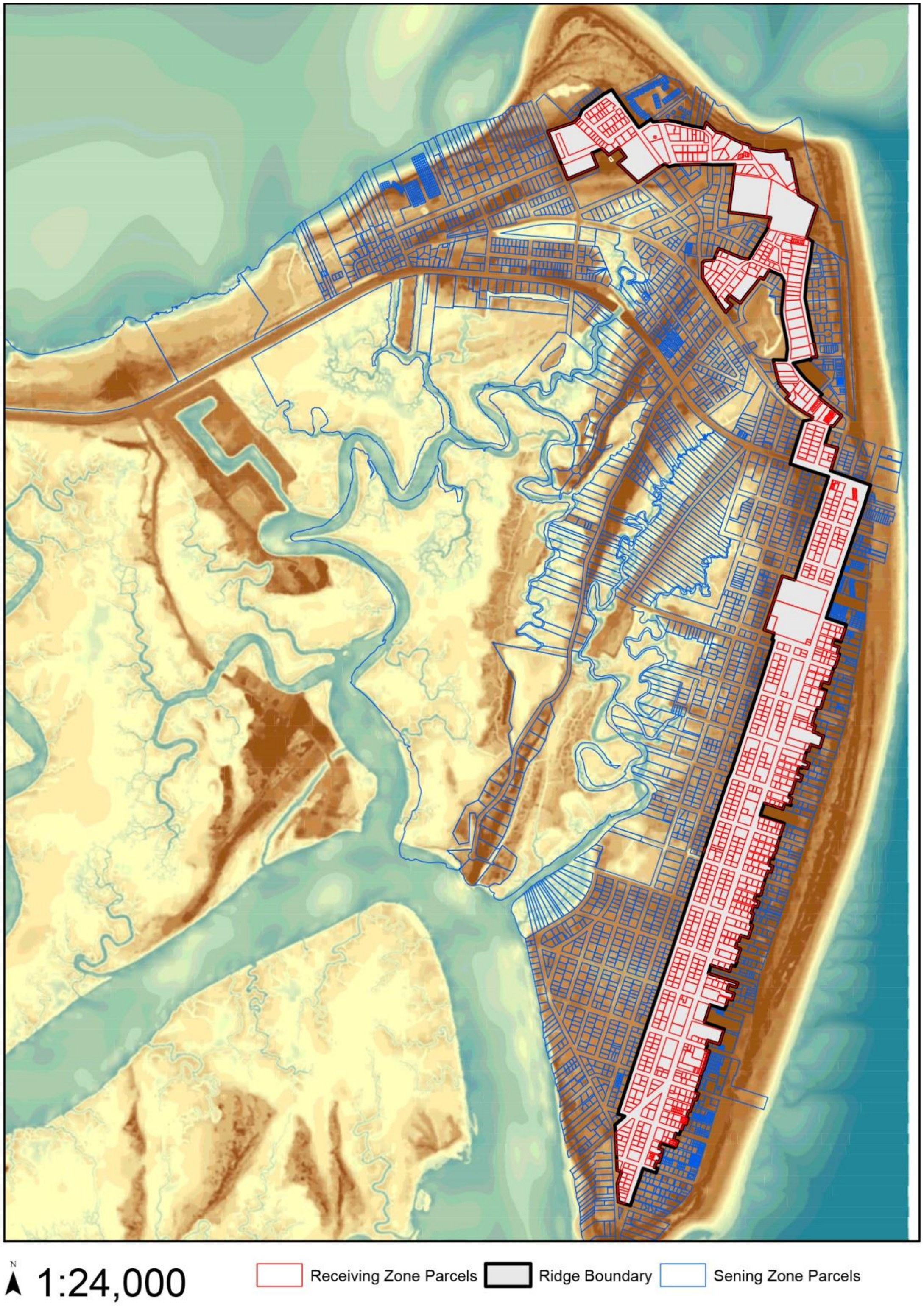


Figure 4.15 (Final Sending Zone and Ridge Armoring Boundary)

The ridge, being an elevated structure in comparison to the flanking marsh and beach, will need to have some sort of interface. There will need to be access points from the ridge to the piers that access the floating homes in the marsh. There will need to be some sort of beach approach access point. The two interfaces will occur at major intersections along the ridge, on opposite sides of the ridge. It will create a sort of N-S promenade, with shorter E-W avenues connecting different approaches to different marsh accessing piers. An example of a beach approach is shown in Figure 4.16. This interface between the beach approaches and the opposite marsh-piers is expressed in Figure Series 4.17.

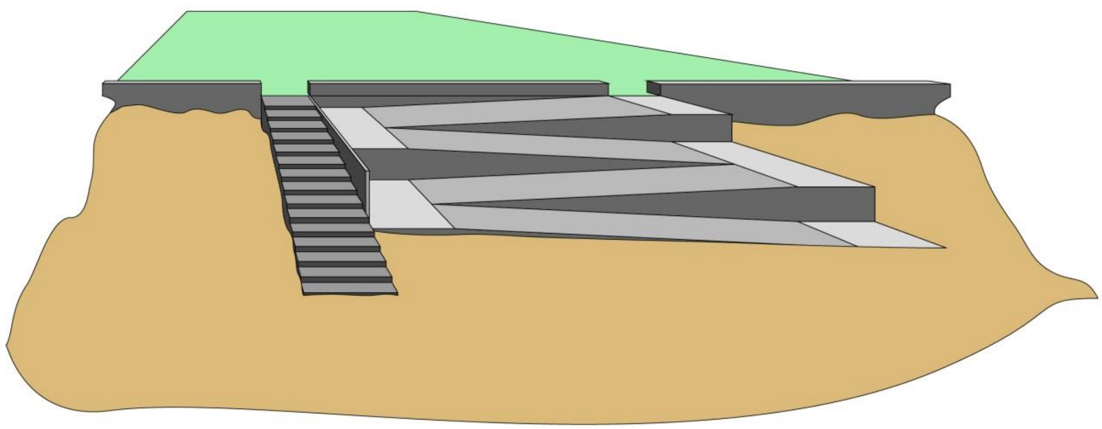


Figure 4.16 (Example of beach approach tactic)

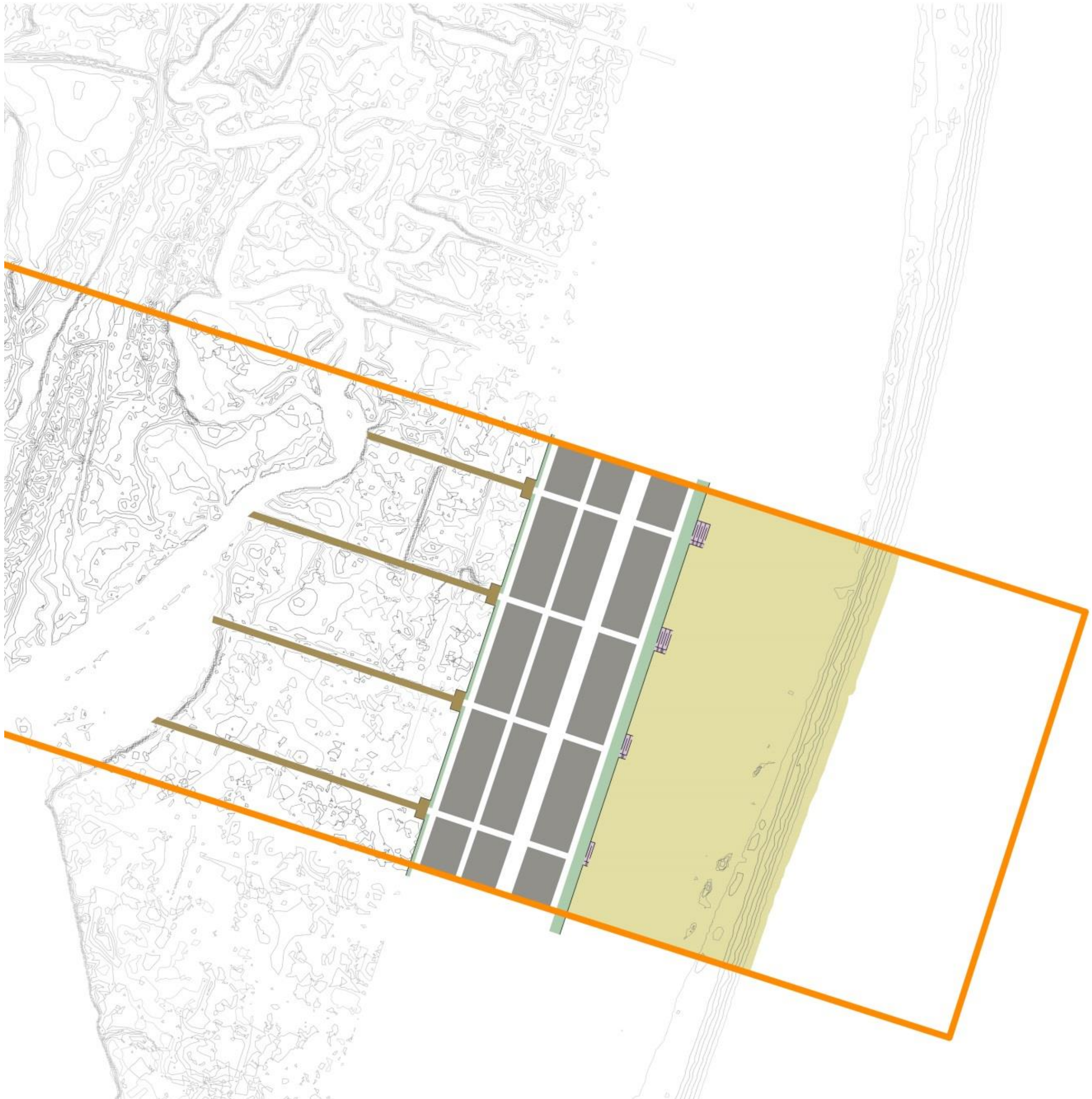


Figure 4.17a (Beach approach and pier interfaces in relation to block structure)

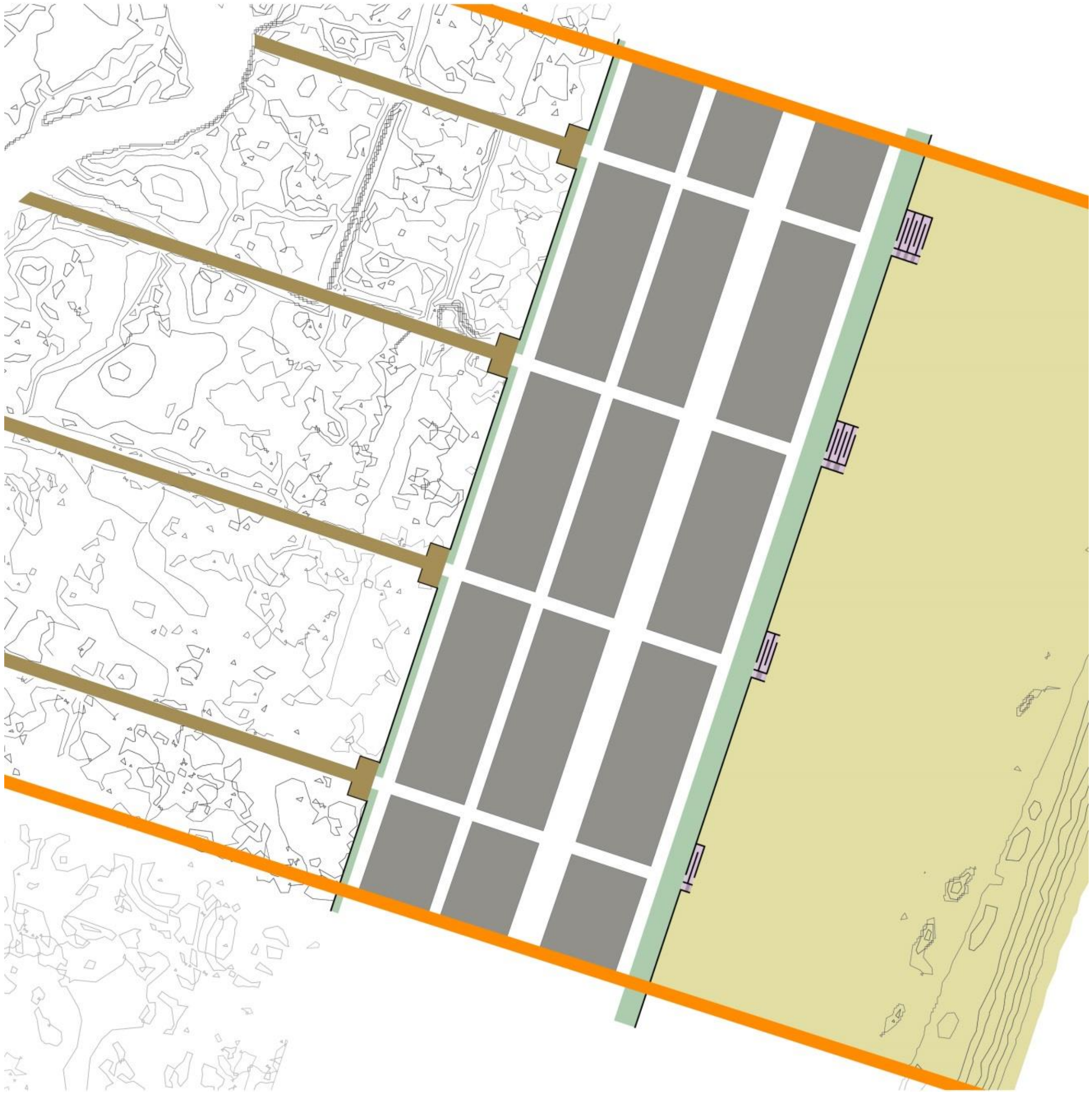


Figure 4.17b (Beach approach and pier interfaces in relation to block structure)

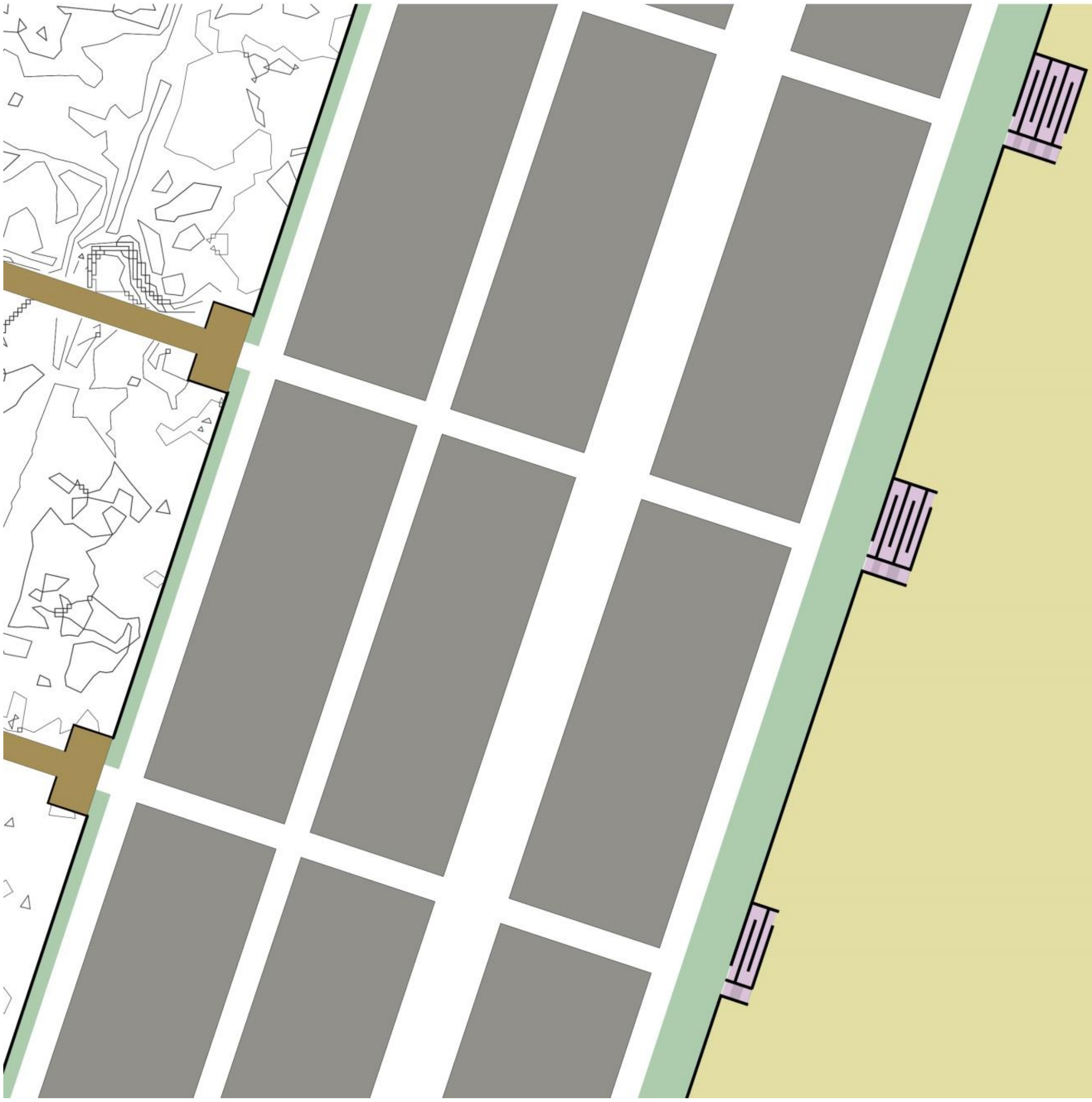


Figure 4.17c (Beach approach and pier interfaces in relation to block structure)

VARIANCES AND TDR CREDIT –

Though physical form is often an underplayed yet vital ingredient to successful cities and developments, policy is the backbone of any operable and functioning city. Policy must be established that addresses what sorts of developmental practice and patterns may emerge in this newly planned block structure on the ridge. Tybee Island is mainly zoned residential at the moment, with pockets of commercial zoning located near the beach and a commercial corridor flanking US highway 80 (the causeway accessing the island). Much of the current real estate of Tybee will be lost. Many homes that are already zoned residential will continue their residential use as floating homes in the marsh. Much of the ridge to be subdivided is currently zoned residential, but in order to recuperate losses due to retreat and to allow businesses that had to retreat from the beach to possibly relocate, commercial development must not only be allowed, but encouraged on the ridge. Figure 4.18 displays the current zoning of Tybee Island. The specifics of the TDR credit plan and the variances it allows are extremely complex, contentious, and complicated. They are not so simple or straightforward to be easily defined in a single chapter. The solution to these issues will not be included in this thesis, but the issues that must be solved can be. How is the zoning organized? Are there specific zones delineated by a master plan, which TDR grants variances for allowing commercial development in a residential zone? How many TDR credits are needed for this variance? Can one upgrade to industrial instead of commercial? Is zoning even an issue regulated by TDR? Do the TDR credits more specifically relate to code? Do they grant variances in things such as setbacks, FAR limits, height restrictions, or balcony space? All of these are questions that must be addressed and contemplated, for with each issue comes several more that are inextricably linked with it. Regardless, this new physicality of Tybee Island will most likely require an entirely rethought zoning map and code regulation, but these things are muted if there is not a flexible and logical physical framework upon which to apply them.

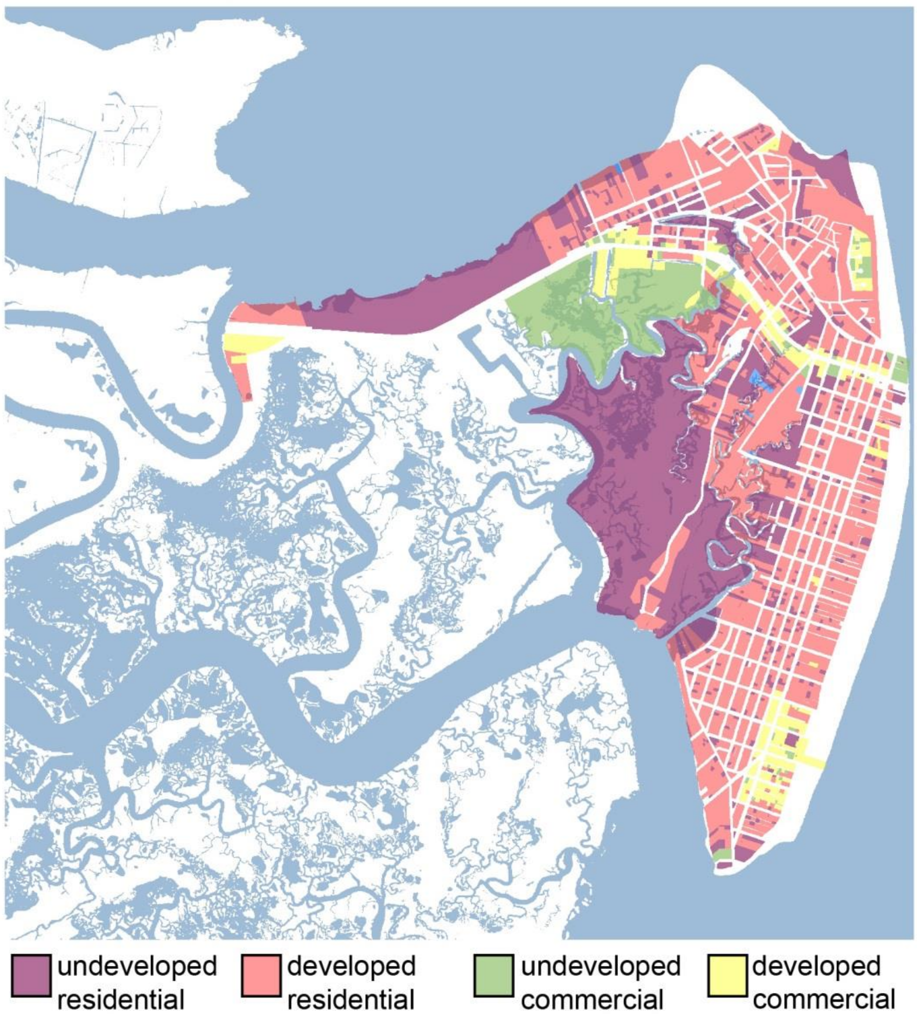


Figure 4.18 (Current Tybee Island zoning)

CHAPTER 5: *FLOATING TYBEE*

A NEW MODEL –

A new type of amphibious architecture specific to Tybee must be developed to be available for post-TDR properties according to the adaptation plan. This new model of home must be livable on land, during shallow and periodic inundation, and during deeper permanent inundation. Several examples of cultures and technologies enabling people to live on water in floating homes exist. The following examples will not always be directly describing models and precedents which adapt to rising sea levels, but contain technologies and principles that will be useful to understand for their application on Tybee. House boats, floating villages, floating neighborhoods, amphibious architecture, and buoyant foundation technology are all things that currently exist today which can be used to piece together a model for living on a future Tybee Island.

LIVING ON THE WATER –

The country which has made the most advances in and has the most occurrences of floating architecture is the Netherlands. The four projects to be examined in the remainder of this chapter are located in the Netherlands and employ technologies that have been nearly perfected by the Dutch, enabling them to build comfortable and beautiful homes on the water. Of these projects, three are developments of floating homes.

GOUDEN KUST AT MAASBOMMEL -

The first project to be examined is the Gouden Kust development at Maasbommel, Netherlands. This project is applicable to this thesis because the Gouden Kust homes are not perpetually situated on water, yet designed to accommodate flooding. This design makes these homes truly amphibious, not aquatic. The homes spend most of the time resting on piers situated just off of a vehicular accessible road on the bank of the Maas River which is prone to high tidal fluctuations and flooding. When the high tide comes in or a flooding event occurs, the house rises with the water level. This idea is made possible by the innovative concrete caissons that the amphibious homes rest upon. These concrete caissons act as cellars for storage during normal terrestrial dwelling periods, but shift to the role of pontoons when flooding events occur.[45] Lightness is a huge factor in the design and construction of these pontoons as well as the design and construction of the timber frame homes that rest on the pontoons, attempting to maximize the efficiency of the buoyancy. The concrete caissons weigh about 72 tons, while the timber frame homes weigh in at about 22 tons.[46] In order to prevent the homes from floating away when a flooding event occurs, there are two guiding poles driven into the ground (in between two neighboring homes) which are tall enough to allow the homes to fluctuate in height with the highest anticipated water levels. The mooring poles which guide the homes during flooding events are shown in Figures 5.1 and 5.2.

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[45] Nillesen, Anne Loes., Jeroen Singelenberg, Gregor Flüggen, Rowan Hewison, and Ilse Crooy. *Waterwonen in Nederland: Architectuur En Stedenbouw Op Het Water = Amphibious Housing in the Netherlands: Architecture and Urbanism on the Water*
[46] "Amfibiewoningen, Maasbommel." *Water in Zicht*

Figure 5.1 *(mooring poles between the caissons of 2 neighboring homes) (boiten.net/watervillas-gouden-kust-maasbommel/)*

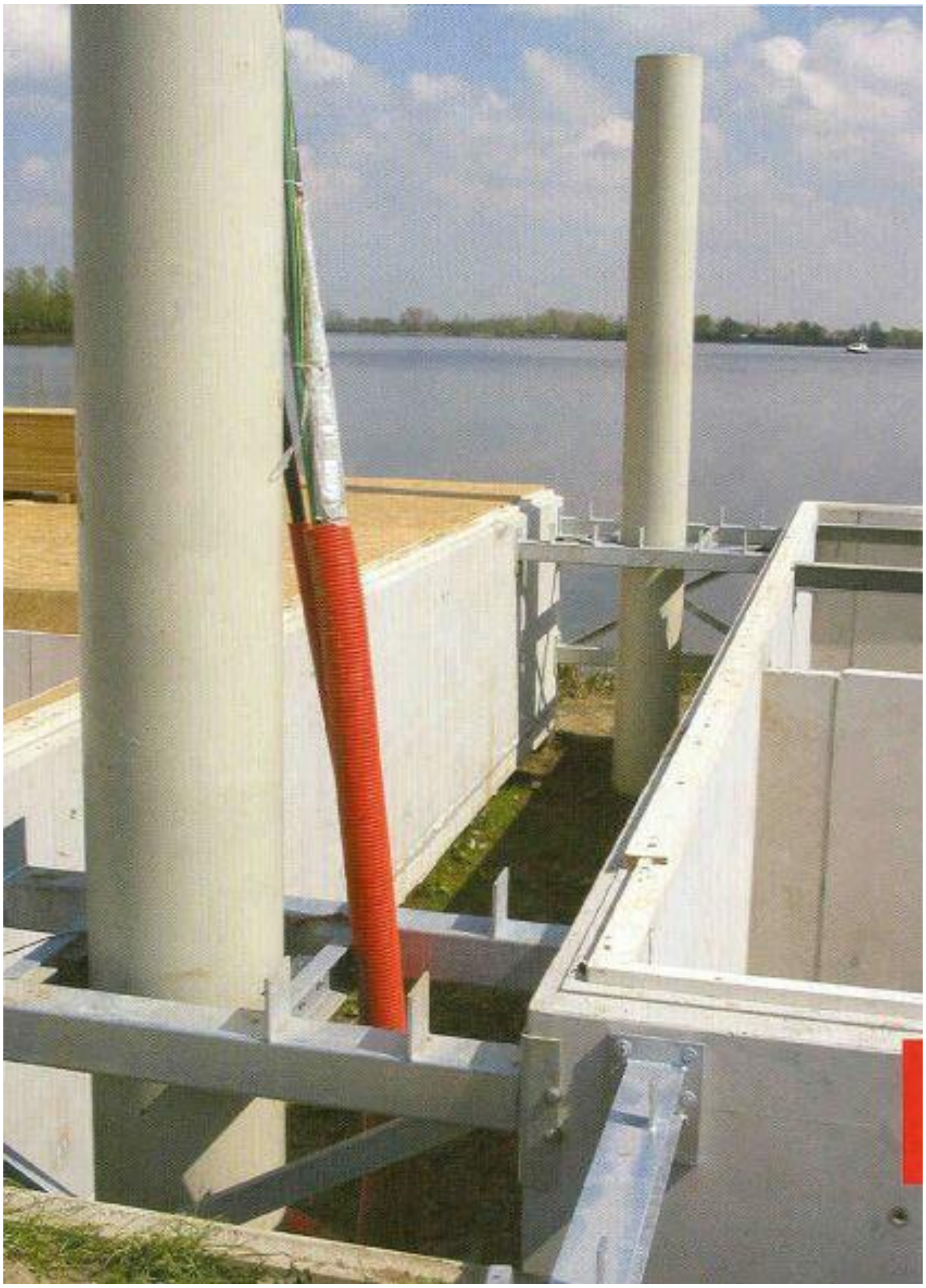

Figure 5.2 *(mooring pole with infrastructure flex piping) (boiten.net/watervillas-gouden-kust-maasbommel/)*

While this system works well for flood damage mitigation, it is not as simple as transferring this technology and methodology over to a home that is expected to have a habitual inundation and rise in elevation due to the presence of raised water levels. This methodology is even less directly applicable when one considers that the homes will eventually move from an occasional inundation and rise due to water levels to a perpetual state of living on water. These homes on the Maas River are inaccessible during flooding events. The mechanisms in place that avert flooding do not take access into account. A diagram showing the procedure of rising with water levels is shown in Figure 5.3. Figures 5.4, 5.5, and 5.6 are images showing the practicality and visual appeal of homes built to withstand and accommodate flooding events.

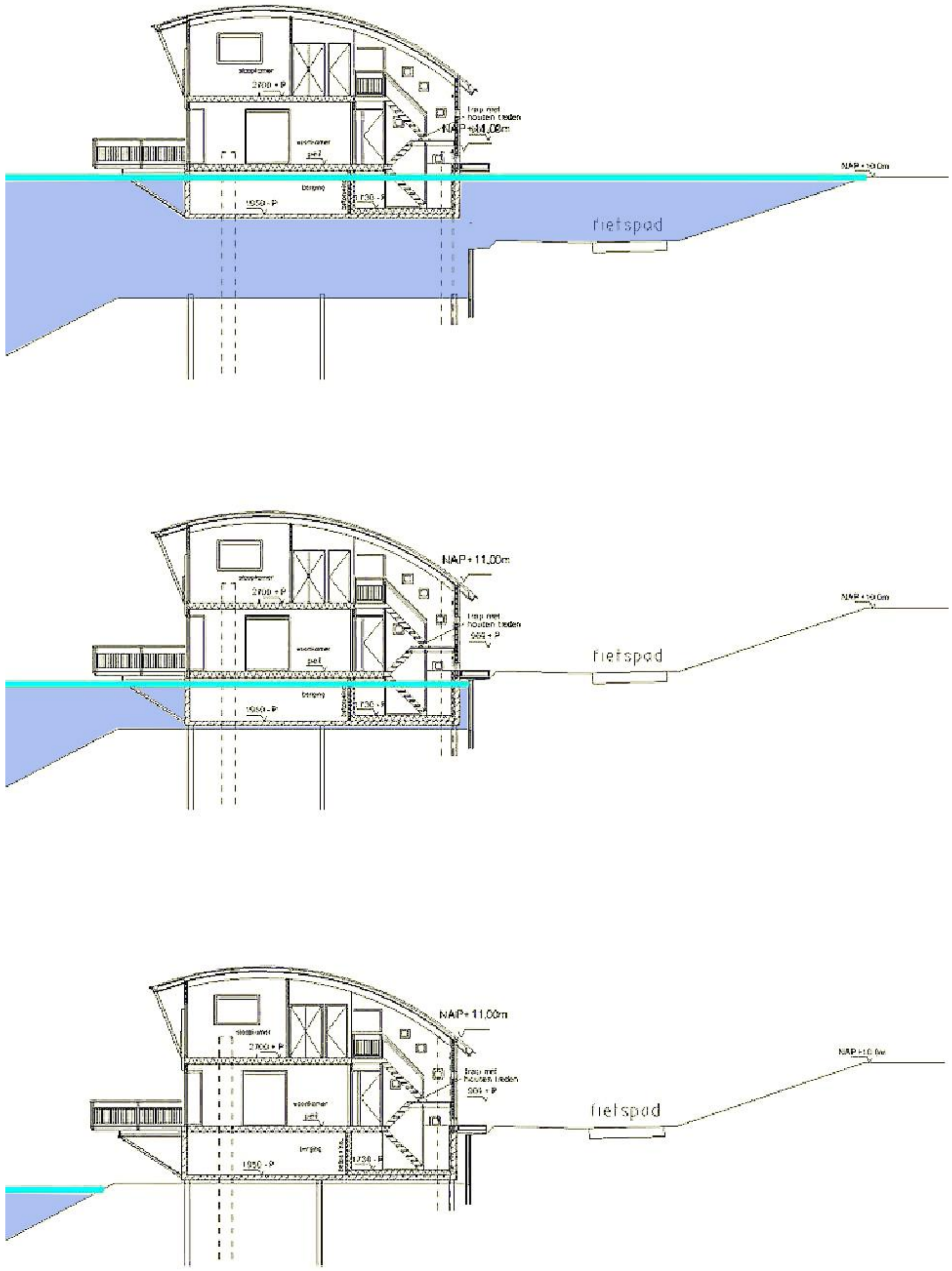

Figure 5.3 *(sectional diagram showing amphibious house rising with water level)*

(boiten.net/watervillas-gouden-kust-maasbommel/)

Figure 5.4 *(boiten.net/watervillas-gouden-kust-maasbommel/)*

Figure 5.5 *(*Nillesen, Anne Loes., Jeroen Singelenberg, Gregor Flüggen, Rowan Hewison, and Ilse Crooy*Amphibious Housing in the Netherlands: Architecture and Urbanism on the Water)*

Figure 5.6 *(*Nillesen, Anne Loes., Jeroen Singelenberg, Gregor Flüggen, Rowan Hewison, and Ilse Crooy*Amphibious Housing in the Netherlands: Architecture and Urbanism on the Water)*

WATERWONINGEN, IJBURG –

Another Dutch housing development that utilizes floating foundation technology to enable life on water is Waterwoningen IJburg. Waterwoningen translates from Dutch to mean "Water Homes", and IJburg is an area on the IJmeer (a lake) in Amsterdam. IJburg is an island built off of dredged sands and is located in the Steigereiland neighborhood.[47] This development is home to differing styles of residences, ranging from expensive single family homes to social housing with a higher density.[48] These houses differ from those previously examined at Gouden Kust because they are perpetually on the water, and this results in some differences in design. The homes (and their utilities) are moored to a jetty with a mooring pole system similar to Gouden Kust, though they are accessible at any water height due to a flexible walk board system. The homes must not draw (have a below water profile) more than 1.5 meters

[47] Nillesen, Anne Loes., Jeroen Singelenberg, Gregor Flüggen, Rowan Hewison, and Ilse Crooy. *Waterwonen in Nederland: Architectuur En Stedenbouw Op Het Water = Amphibious Housing in the Netherlands: Architecture and Urbanism on the Water*.
[48] "Architectenbureau Marlies Rohmer : / Home /." *Architectenbureau Marlies Rohmer : / Home /*.

and float on a buoyant concrete caisson system which doubles as living space. Half of the bottom floor's (the caisson) profile is underwater. Sections and floor plans of a typical home in this IJburg development is shown in Figure 5.7.

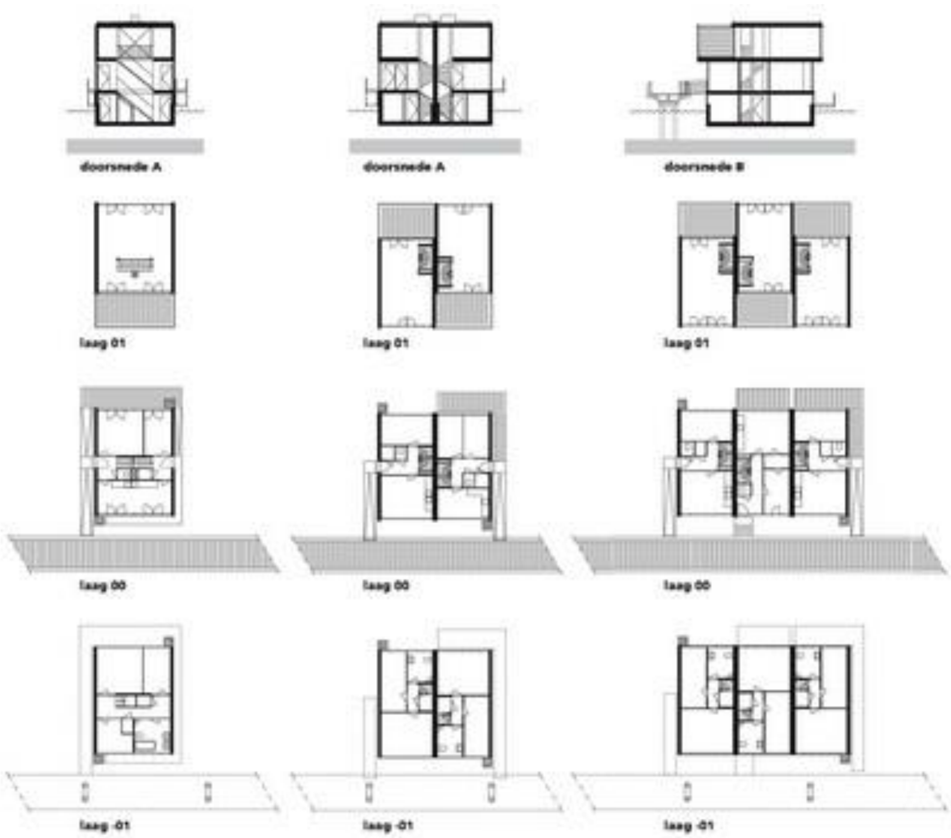

Figure 5.7 *(Floors -1, 1, and 2 and Cross Sections of a typical IJburg home)* *(http://www.rohmer.nl)*

The homes in the IJburg development are able to be towed to and from mooring sites at the development. Though this is not a cheap endeavor, the possibility of relocation, repairs, emergency evacuation, among other things is present with the towing capability. This capability is shown in Figure 5.8.

Figure 5.8 *(an IJburg home being towed to the development after offsite construction)*

(http://www.rohmer.nl)

Figure 5.9 *(http://www.rohmer.nl)*

Figure 5.10 *(http://www.rohmer.nl)*

MAASVILLAS AT OHE EN LAAK –

The Maasvillas at Ohe en Laak are a sort of combination of the two previously identified projects. This housing development is considered an amphibious development and was executed by the same contracting company which did Gouden Kust. The difference between Maasvillas at Ohe en Laak and the two previously identified projects is that while these homes are perpetually on the water, they are not perpetually floating. There are 32 villas constructed in this development, 16 of which are considered "floating" while the other 16 are considered "semi-floating". The "semi-floating" buildings are very similar to those at IJburg, but during normal water levels they rest on concrete pile foundations. When the water level rises, they rise much like the homes at Gouden Kust, and when the water returns to normal, they return to their submerged, water-level concrete piles.[49] The homes seem to be perpetually aquatic, though they only float during flooding events. Figures 5.11-5.14 show the floating conditions through section, the placement of homes on their piers via a crane system, and their aesthetics and arrangements respectively.

Figure 5.11 *(floating section) (http://www.duravermeerbouwrosmalen.nl/projecten/)*

[49] "Dura Vermeer Bouw Rosmalen BV Projecten." *Dura Vermeer Bouw Rosmalen BV Projecten*.

Figure 5.12 *(home being placed on piers by crane) (http://www.maasvilla.nl/villas)*

Figure 5.13 *(http://www.maasvilla.nl/villas)*

Figure 5.14 *(http://www.maasvilla.nl/villas)*

WATERVILLA AMSTELDJIK –

The final project to be looked to as an example of the feasibility, practicality, and desirability of building and living on water is an individual home on the Amstel River which flows through Amsterdam. The "Watervilla Amsteldjik" is actually a project that is two separate houses on a common floating foundation. The floating foundation is a semi-submerged basement space which accommodates the bedrooms and bathrooms. Right above the waterline there is a continuous window which allows light into the basement bedrooms. The model made by the architect demonstrates the spatial layout of the building in Figure 5.15.

Figure 5.15 *(exploded model showing spatial layout ROOF PLAN/FLOOR1/BASEMENT) (http://www.plus31architects.com/)*

This type of housing is unique to the aforementioned typologies because it does not require a mooring pole. This building has a much lower center of gravity than the others, being that it is only two floors. This low center of gravity would increase stability, freedom, and tow ability. The fact that it is only two floors cuts down on the square footage available, making the design and layout of the home even more important. This house is designed very well with a nice open layout as visible in the interior shot shown in Figure 5.16. The façade of the building, and the landward approach are also nicely designed, demonstrated in Figures 5.17 and 5.18.

Figure 5.16 *(interior shot) (http://www.plus31architects.com/)*

Figure 5.17 *(riverside façade) (http://www.plus31architects.com/)*

Figure 5.18 *(landward approach) (http://www.plus31architects.com/)*

SEGWAY –

These homes show that living in a floating home can be a desirable and pleasing reality. The technology exists, as does the culture. The trick to using these models is to figure out how their principles can be injected into the culture and conditions of Tybee. Each of these examples is very site specific. The amphibious architecture to be devised for Tybee must be site specific as well. The site, conditions, role within the TDR scheme, parcel size, and culture must all be evaluated and allowed to inform guidelines and rules for development and design.

GUIDELINES FOR DESIGN –

There is certain criterion that must be met for a Tybee Island specific amphibious house to be livable, functional, and enjoyable. The criteria established is working within the bounds of the adaptation plan previously proposed. . The house must be an adequate replacement for the terrestrial home to be sold by an owner in a sending zone. The home must also be adaptable and flexible, for not only does it have to be a desirable terrestrial home, but it has to be a desirable floating home as well. The transitional period between full time terrestrial dwelling and full time aquatic dwelling is another enormous challenge to be addressed by this new architecture. In order to fulfill this role as a functioning and desirable amphibious home, certain criteria has been identified: Capability to Float; Entrance Height; Float Line; Structure Type; and Utility Access.

CAPABILITY OF FLOATING –

The most critical design guideline and factor is whether the home will actually be able to float. Using two mooring poles as an aid to stabilization, as was seen in the Gouden Kust and IJburg projects, leaves only a simple buoyancy calculation to evaluate whether the home will float. If the weight of the entire home is less than the weight of a volume of water equivalent to that displaced by the home than the home will float. In order for this buoyancy calculation to accurately predict whether something will float, it must be water-tight. This is the main challenge of designing amphibious homes. A water tight ground floor must be designed that is structurally independent and without need of a foundation. This is why a special concrete caisson with built in 1st floor walls is used, as shown in Figure 5.19. The Caisson is water tight, made of light weight concrete with hollow cores pre-cast into it. It acts as a slab and foundation walls, and doubles as a water tight barrier.

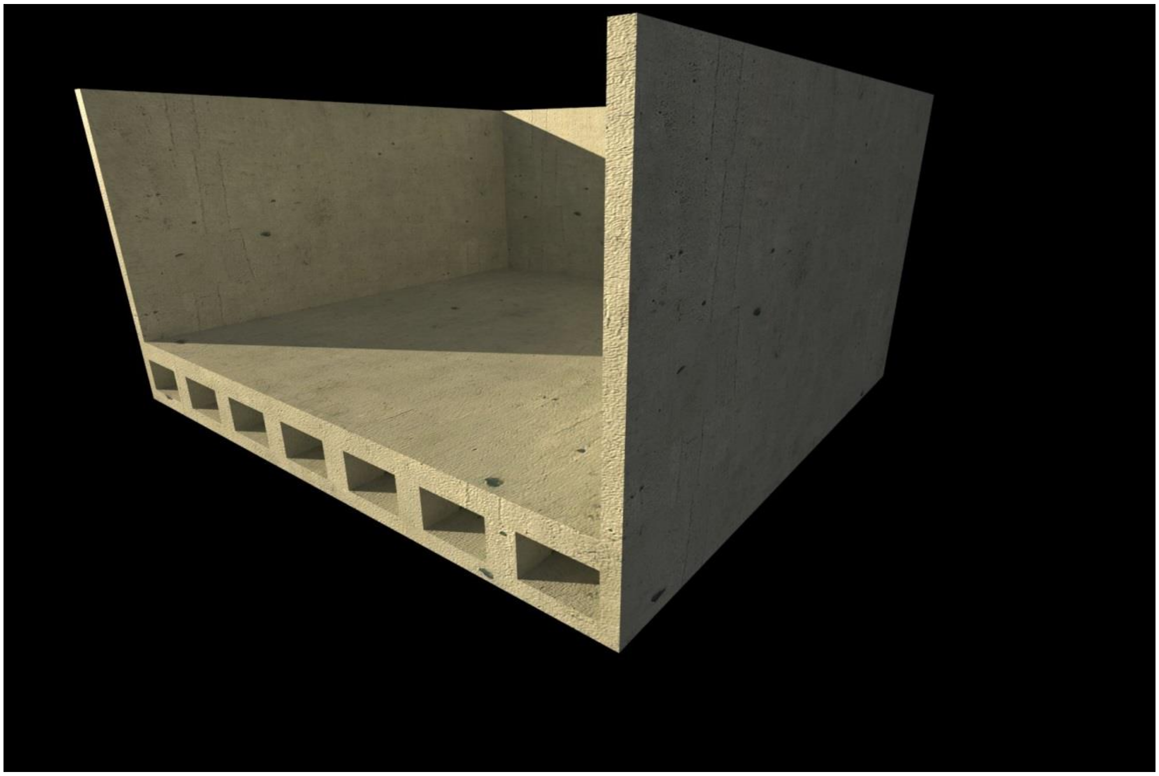

Figure 5.19 *(cross section of a light weight concrete caisson showing hollow cores)*

ENTRANCE HEIGHT –

The entrance height is the section criteria to be established for any property owner wishing to build a new water proof home. Though the public rights of way will remain for a considerable amount of time, at some point vehicular access to these homes will be impossible. It is at this point that public piers will be the right of way to access these marsh homes.   The pier will be emerging from the ridge which is at 17 feet above sea level. For this reason, the entrance to these homes will be at 17 feet.

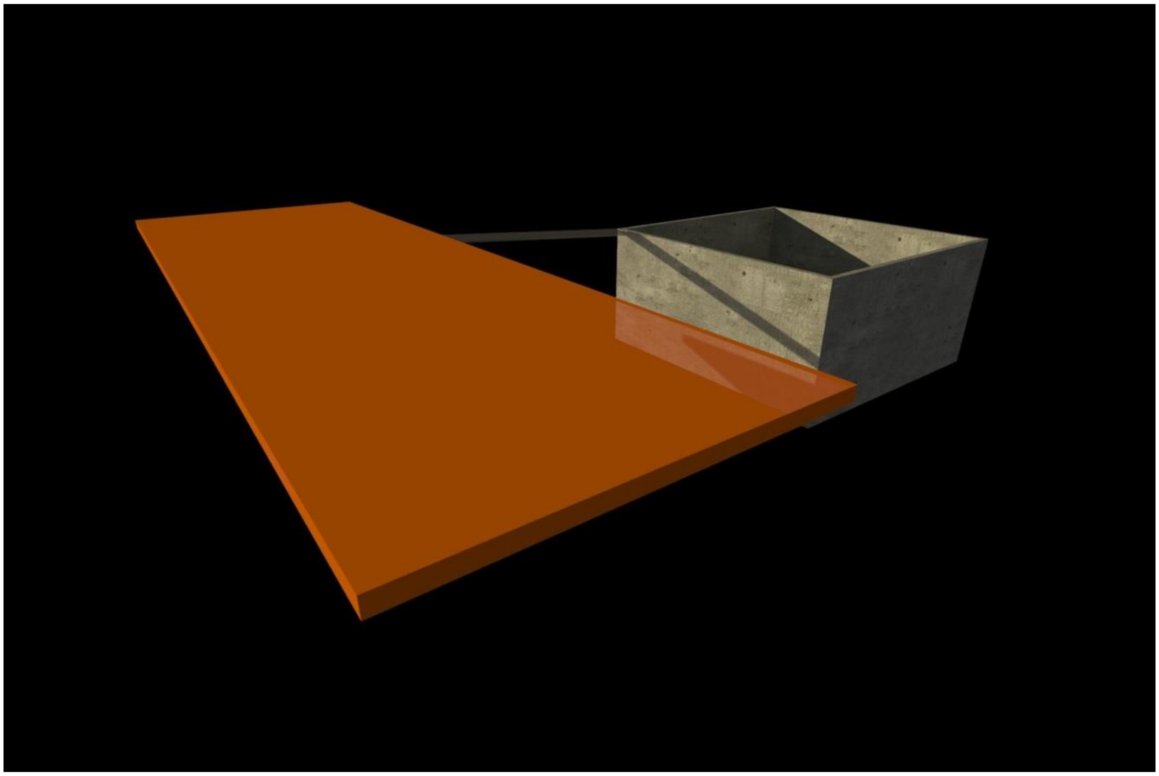

Figure 5.20 *(diagram showing jetty access in relation to pier)*

FLOAT LINE –

The third criterion to be standardized across marsh development is the "float line".   The float line is the line that denotes when the building will begin to float. According to the buoyancy principle, if an object displaces a volume of water which weighs greater than that object it will float. Likewise, if an object displaces a volume of water that weighs less than the object, it will not float. Since a buildings square footage is static, the only variable that will alter the volume of water displaced is height. This means, that is the sea level rises, more volume is displaces, thus more weight So as the sea rises, the building moves closer and closer to floating. There is a certain point at which the volume displaced equals the weight of the building, and it will float. This can be controlled, and needs to be so that the homes to be built in the marsh do not have such a low float line that they create steep grade between the entry and the pier. The float line is to be designed for five feet below the pier, at 12 feet. This is to maintain a 1 to 6 pitch at worst case scenario. If the water rises and the grade becomes steeper, it will not matter because the pier will be completely inundated at that point anyways. This concept is demonstrated in Figures 5.21.

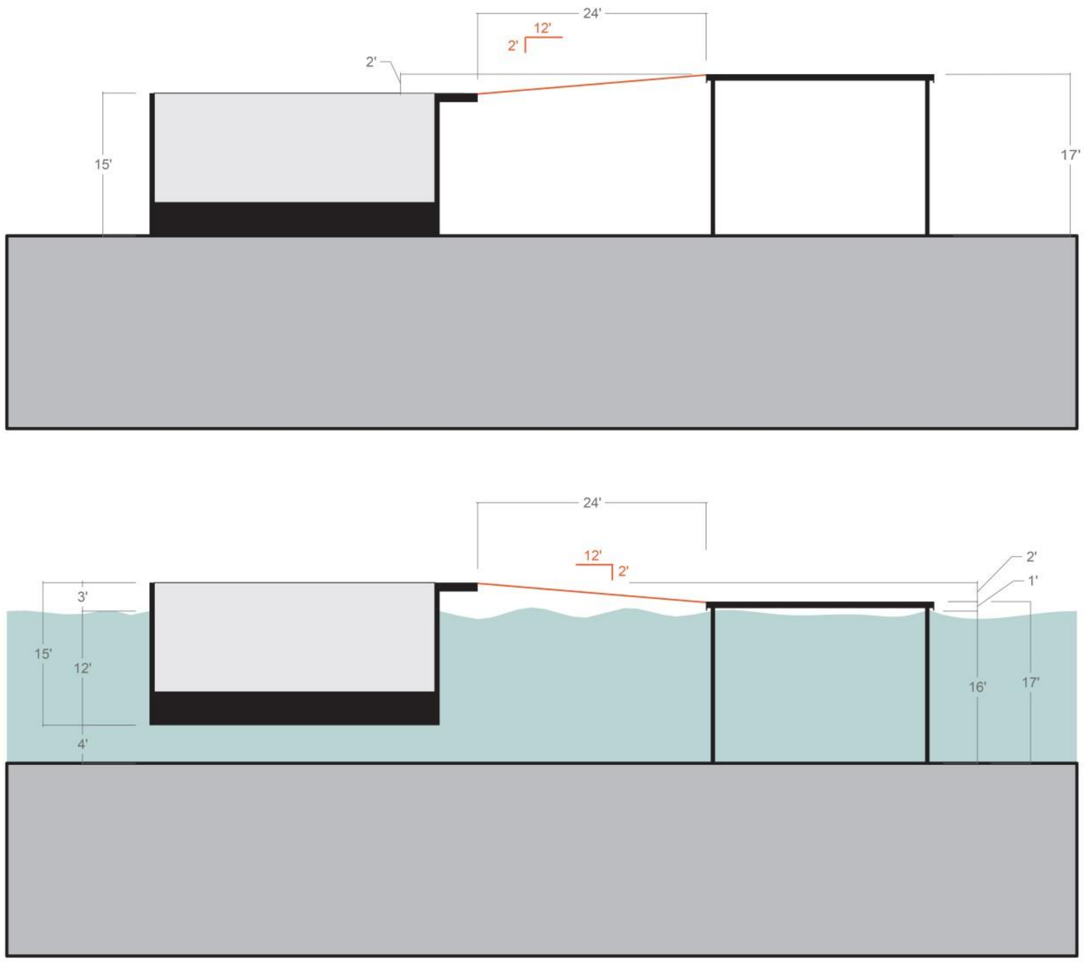

Figure 5.21 *(diagram showing a designed float line controlling pitch between entry and pier)*

STRUCTURE TYPE –

In order to design for a specific float line, lightweight materials must be used. This is why lightweight concrete is used when concrete is necessary, and why the caisson has hollow cores. A further measure to reduced weight is to mandate that all construction be light-wood framing. This is a typical tactic in the Netherlands. A schema of the general construction method is shown in Figure 5.22.

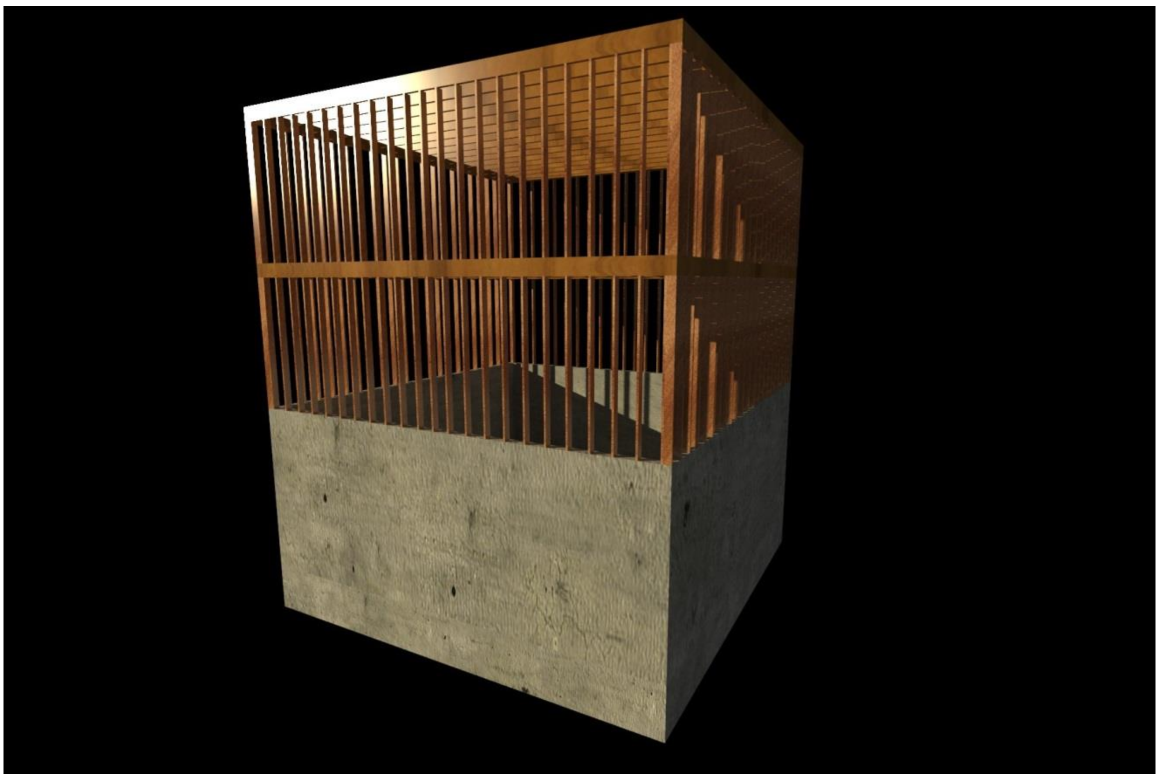

Figure 5.22 *(Light wood frame construction to assist in controlling float line.)*

UTILITIY ACCESS –

The final criterion that is critical to successful regulation and development of the marsh is to standardize utility access points and methods. Due the public right of way eventually shifting to being the pier leading off of the ridge into the marsh, the entrance to these floating homes will be limited to facing the pier/current street. The utilities will use this forced access point into the home to run water, sewage, and electricity. This is a necessary step because modern practices of burying utilities will not be adequate for life on the water. Some sort of system for utility access has to be developed that is functional on land and in water. Using the building entry as an access point for utilities allows the future possibility of running the utilities under the gang-plank between the home and the pier. This criterion is shown in figures 5.23-5.25.

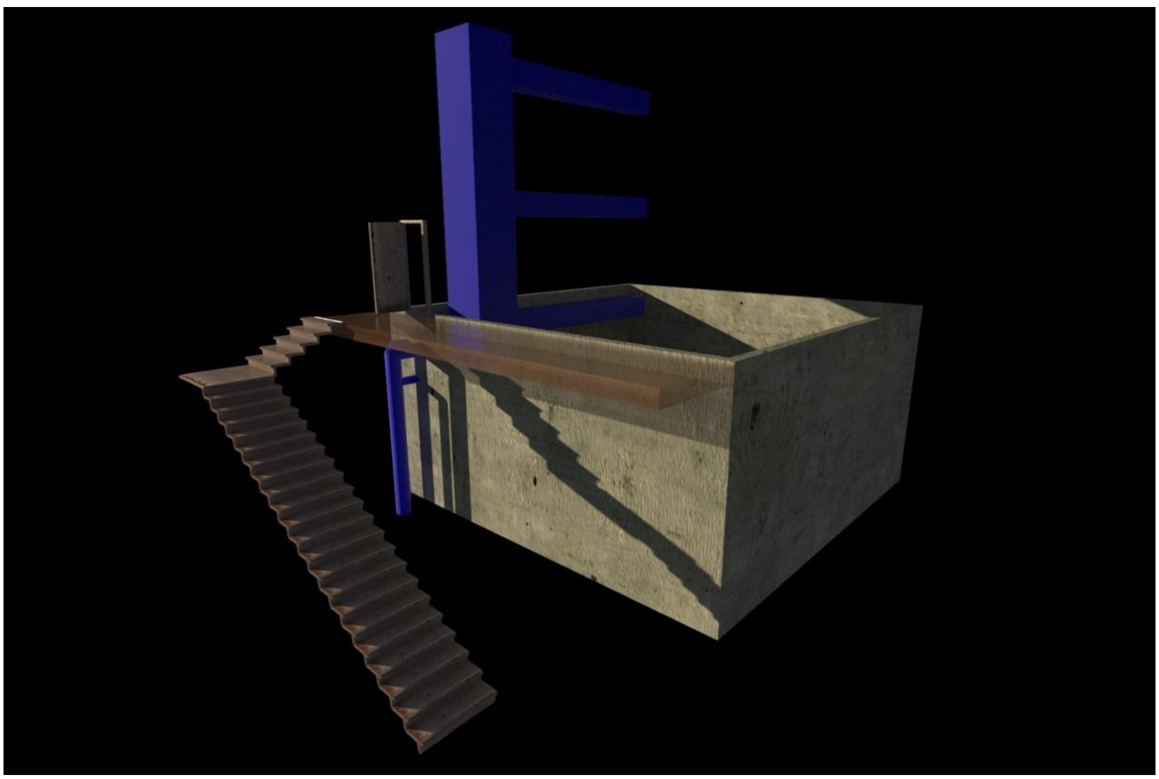

Figure 5.23 (3D diagram of utility chase location within a prototype home)

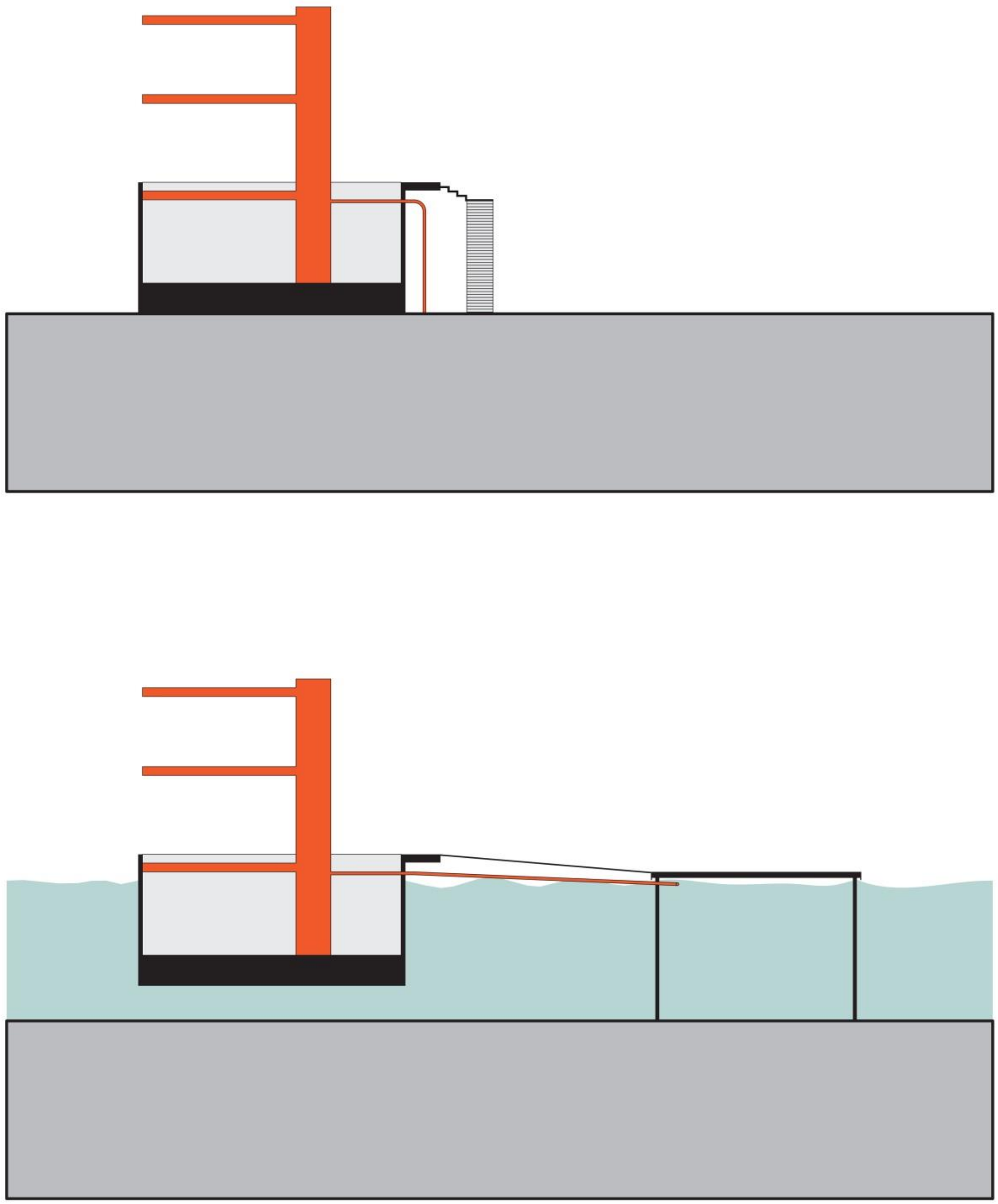

Figure 5.24 *(Sectional diagram showing utility functionality on land and in water)*

These criterion are important to standardized so that any future development in the marsh is not hap-hazard and unplanned, but regulated and logically thought out. It is crucial that things such as heights, utility access points, easements for new pier public rights of ways, float lines, foot prints, and other items are uniform across the development, so to make easy and flexible any future adjustment, planning moves, and unforeseen circumstances. Despite these criteria being standardized, there is still much room for variability and uniqueness. The following three prototypes utilized different programs and demonstrate the ability of these homes, though uniform in certain regards, to be tailored to suit the individual.

A NEW MODEL –

HOUSE 1 –

House 1 is a model showing 2 bedrooms, 2.5 baths with a library, kitchen, and office. The kitchen, library, dining room, and office are all on the basement level and only accessible via the stairs from the entry landing. This is shown in Figure 5.25.   The master bedroom and the living room occupy the main entry floor, as well as a private back deck. The front porch, used for entry is located on this level as well, displayed in Figure 5.26. Figure 5.27 describes the top floor which houses the guest bedroom and bath, as well as open space to be used by the owner at will. Figures 5.28-5.29 describe elevations and sections of this home. Figures 5.30 is a rendering of this home.

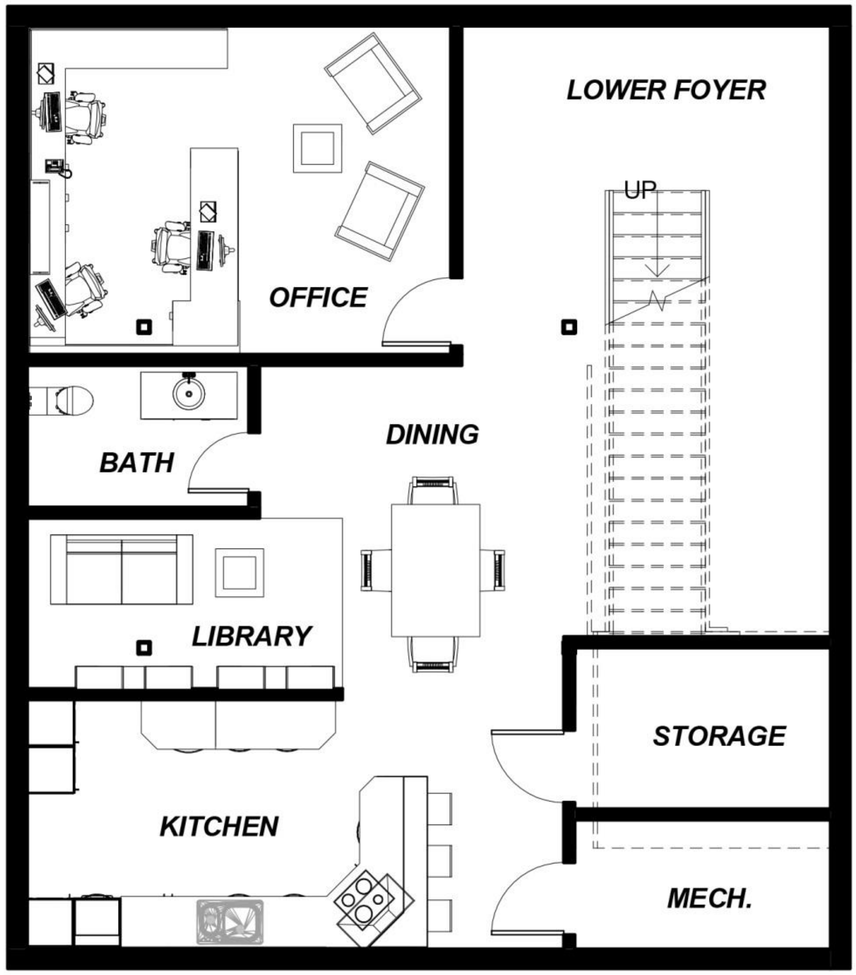

Figure 5.25 *(House Prototype 1: Basement)*

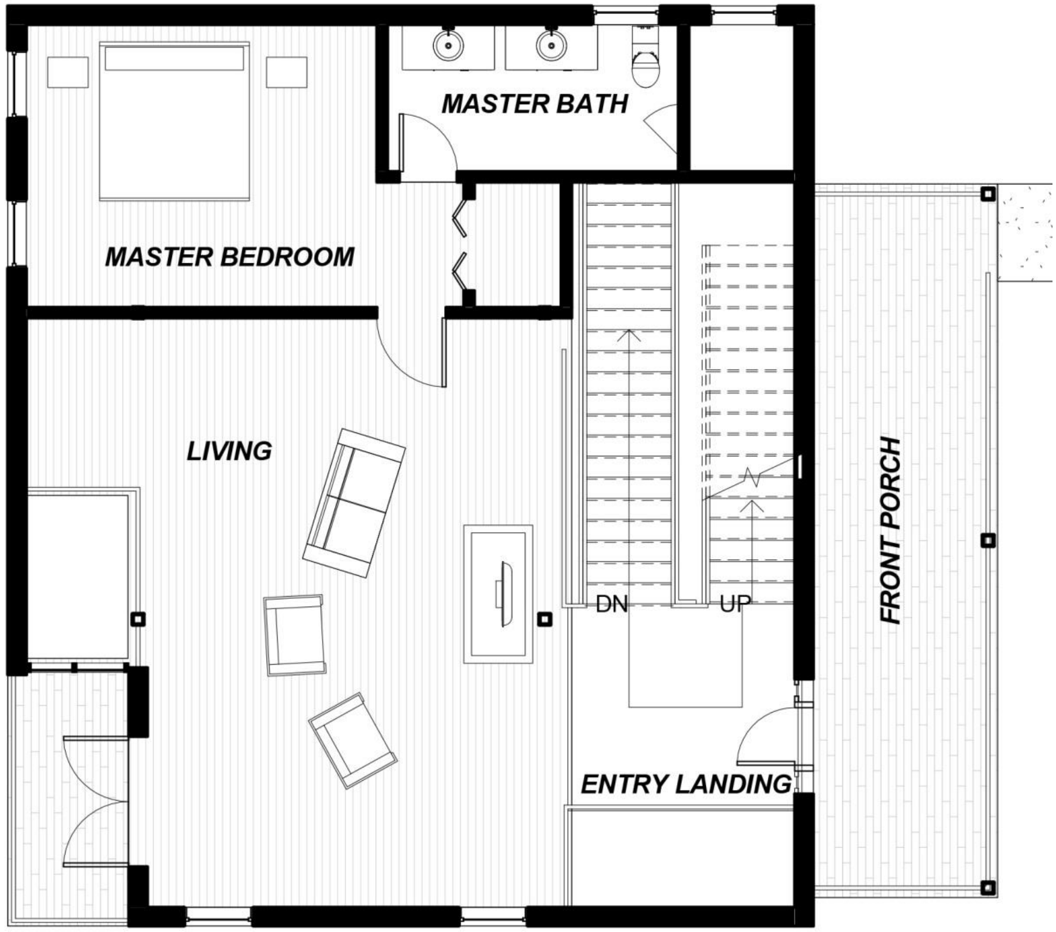

Figure 5.26 (*House Prototype 1: Entry)*

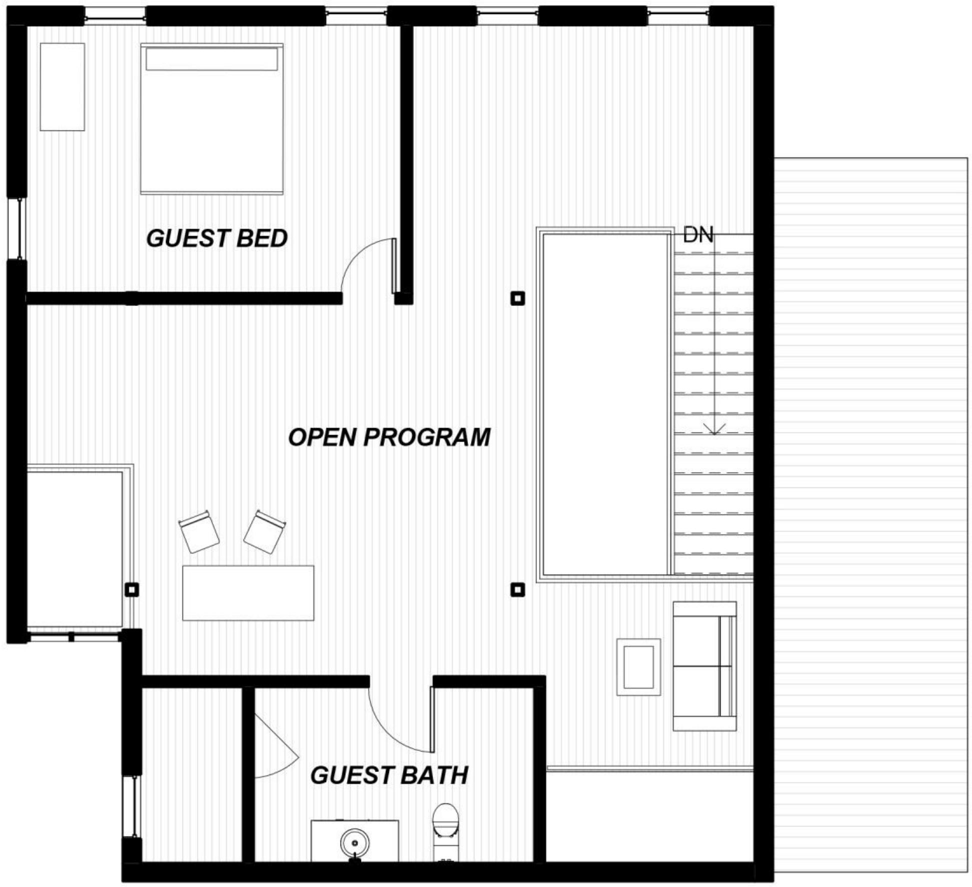

Figure 5.27 *(House Prototype 1: Level 3)*

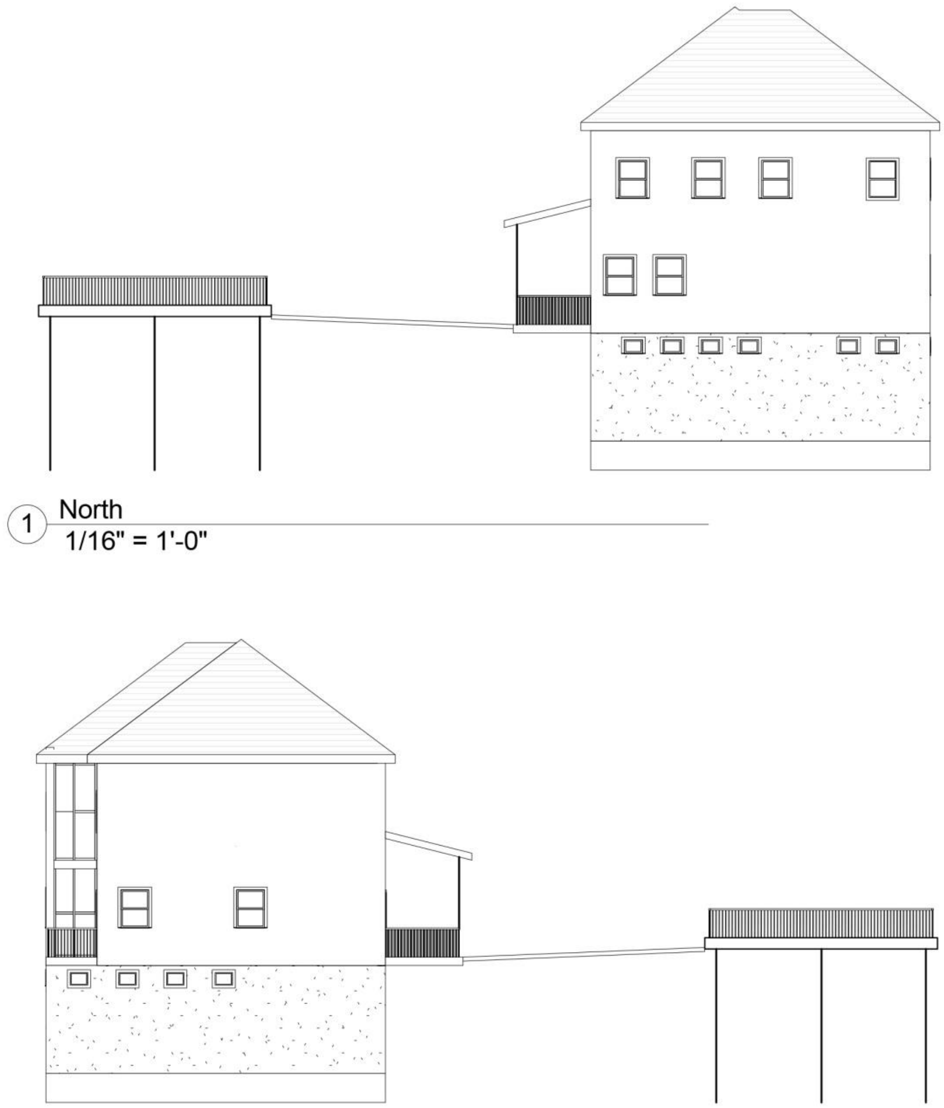

Figure 5.28 *(House Prototype 1: North and South Elevations)*

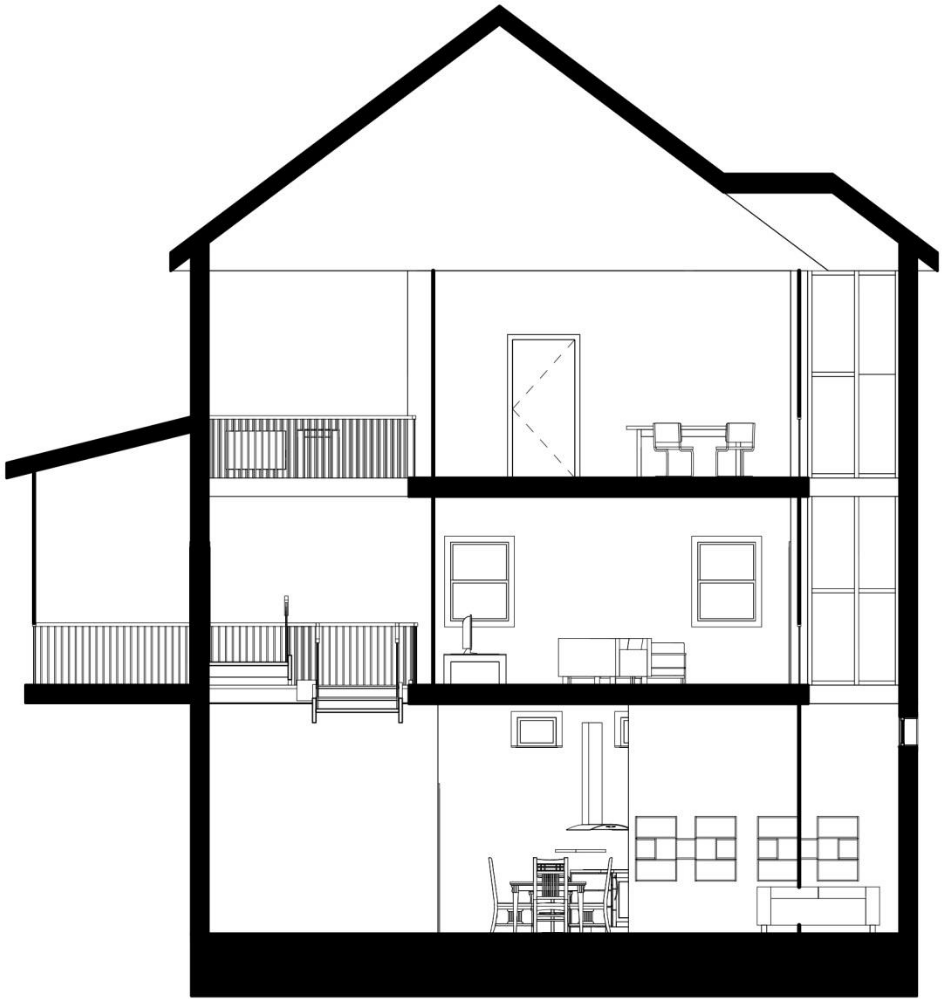

Figure 5.29 *(House Prototype 1: Section)*

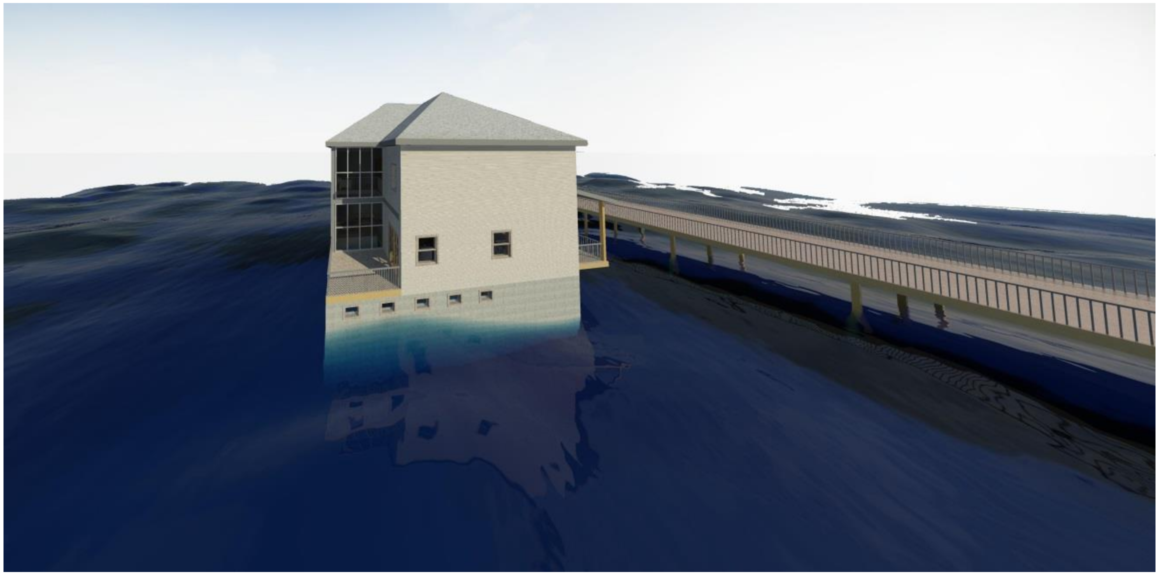

Figure 5.30 *(House Prototype 1: Exterior Rendering)*

HOUSE 2 –

Prototype House 2 is a bit bigger than prototype 1. It is designed for more people. With 3 beds and 2.5 baths, the basement floor is occupied by two guest bed rooms, a guest bath, storage, a mechanical room, and some open program space. The entry level contains the kitchen, dining room, living room, a half bath, and a covered porch. The third floor is the master bedroom, the master bath, some open program, and a green house. Figures 5.31-5.38 are the architecture drawings describing this home. Figures 5.38-and 5.39 are exterior renderings.

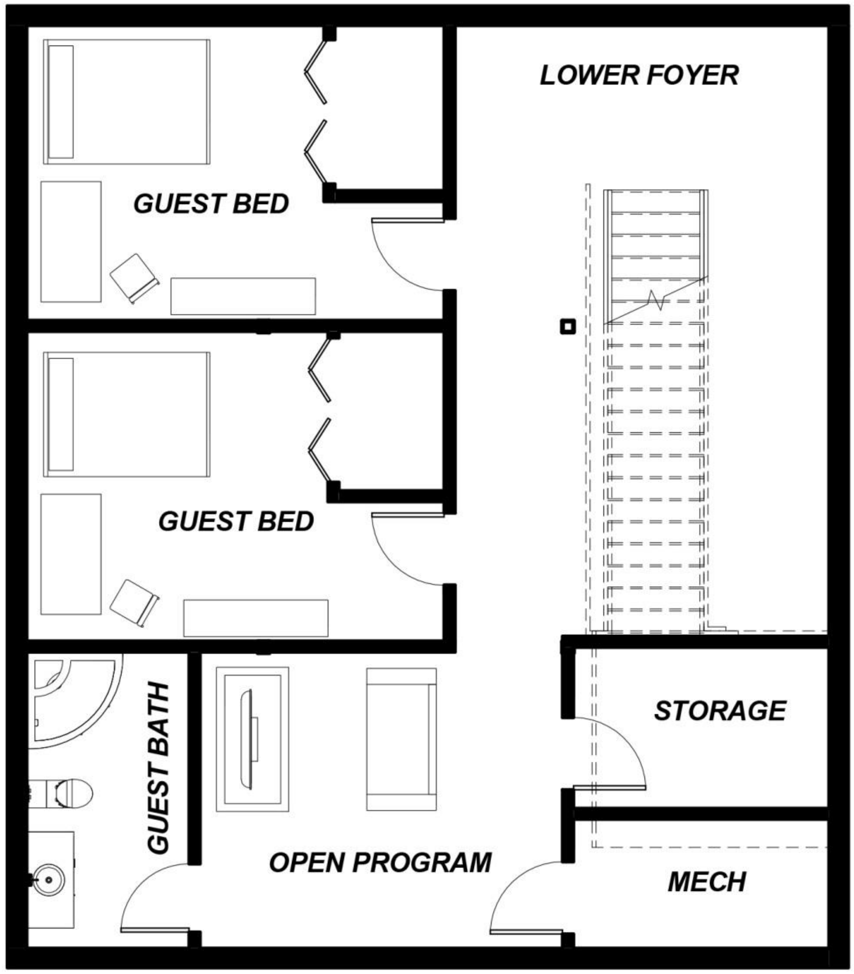

Figure 5.31 *(House Prototype 2: Basement)*

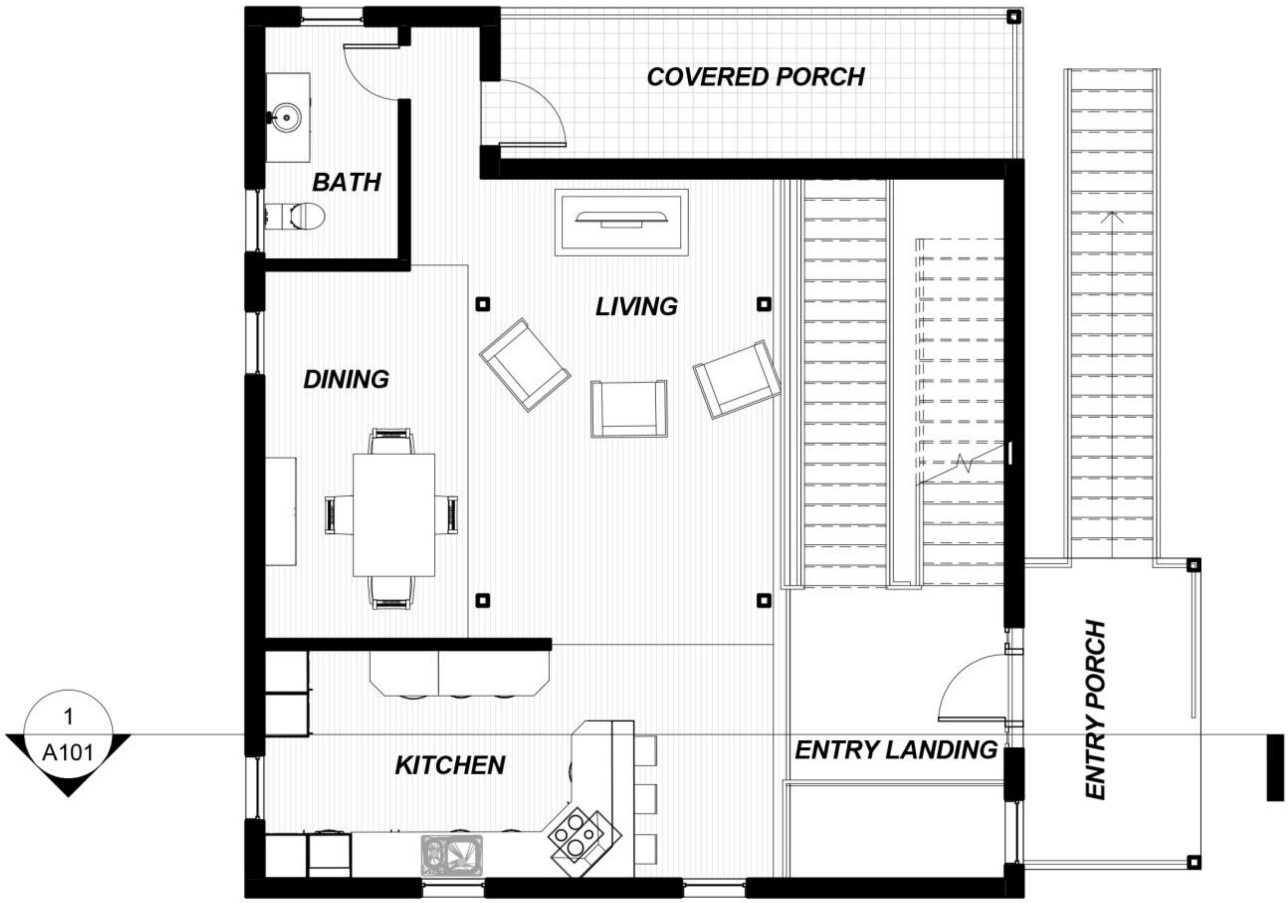

Figure 5.32 *(House Prototype 2: Entry Level)*

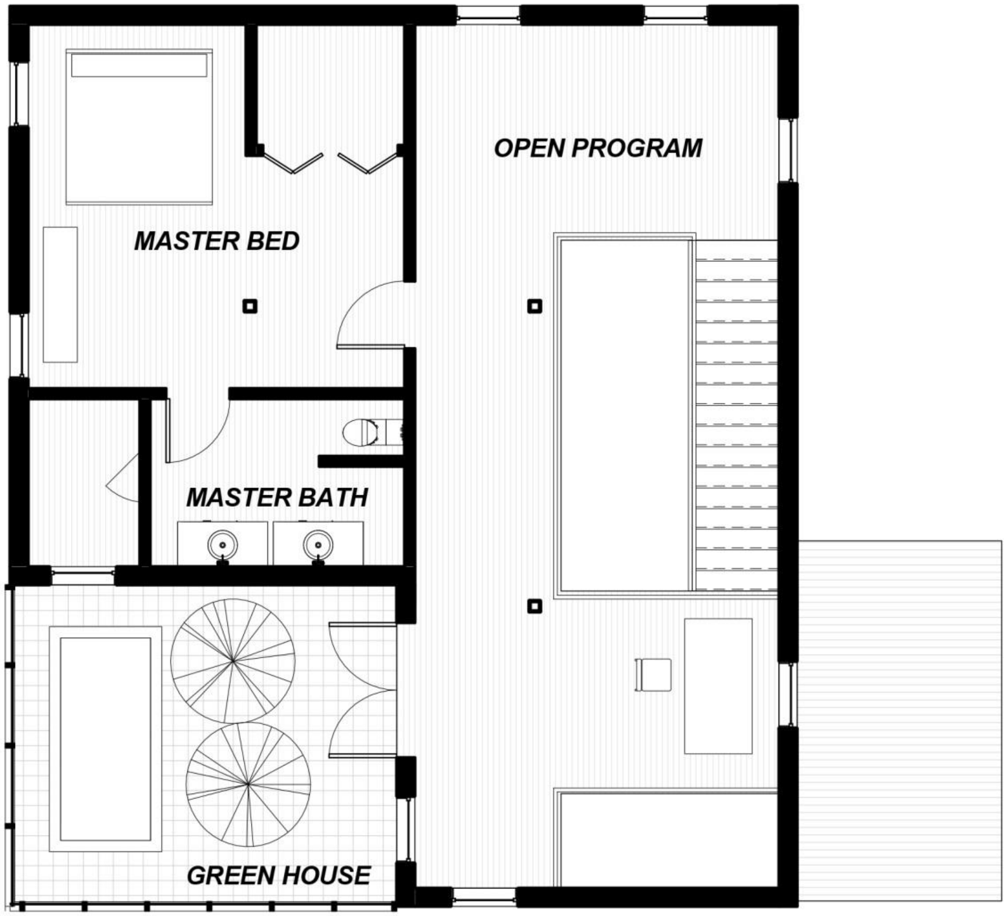

Figure 5.33 *(House Prototype 2: Level 3)*

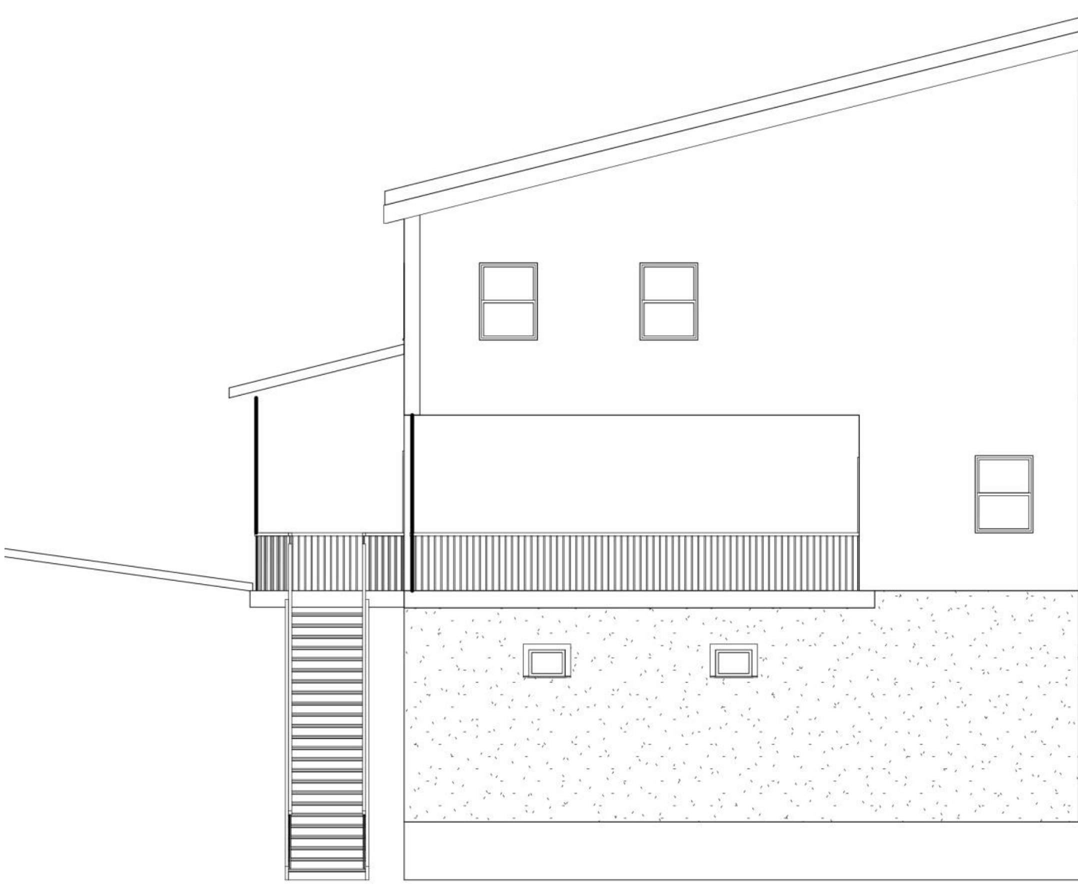

Figure 5.34 *(House Prototype 2: North Elevation)*

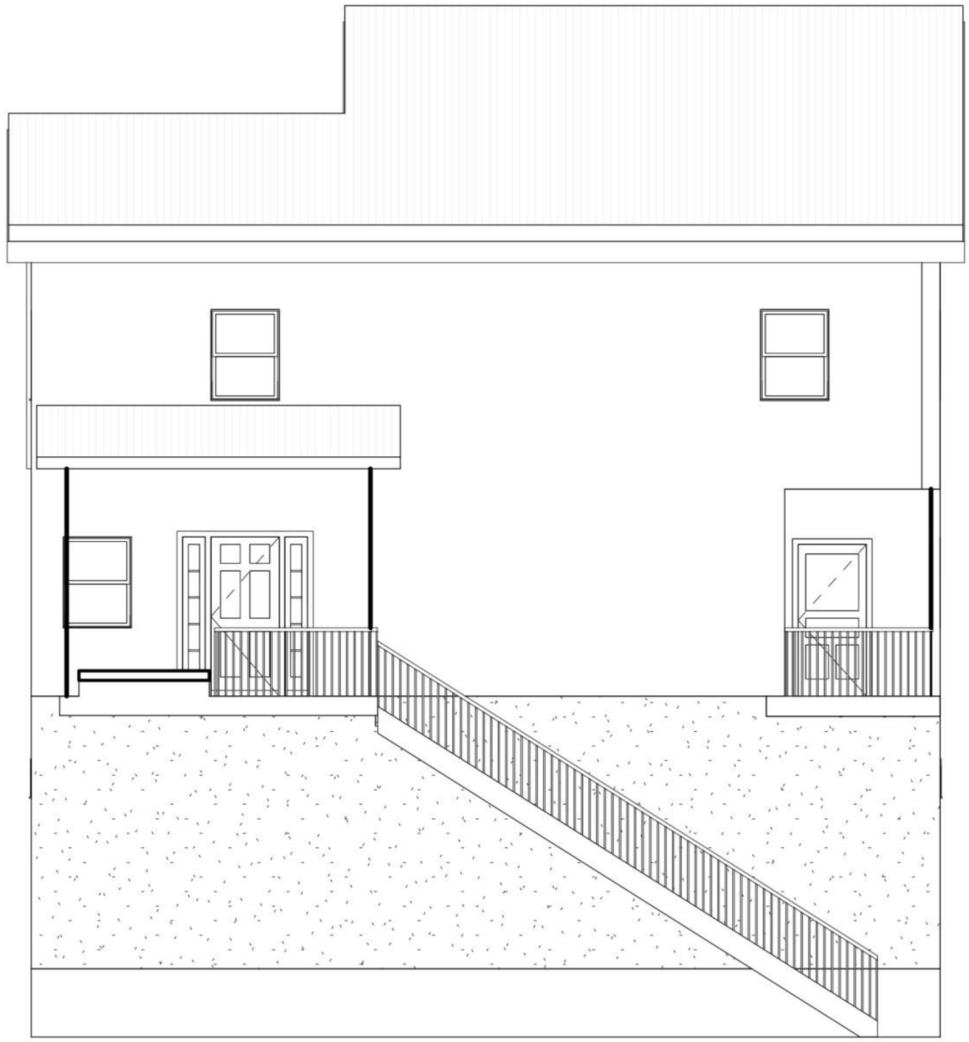

Figure 5.35 *(House Prototype 2: East Elevation)*

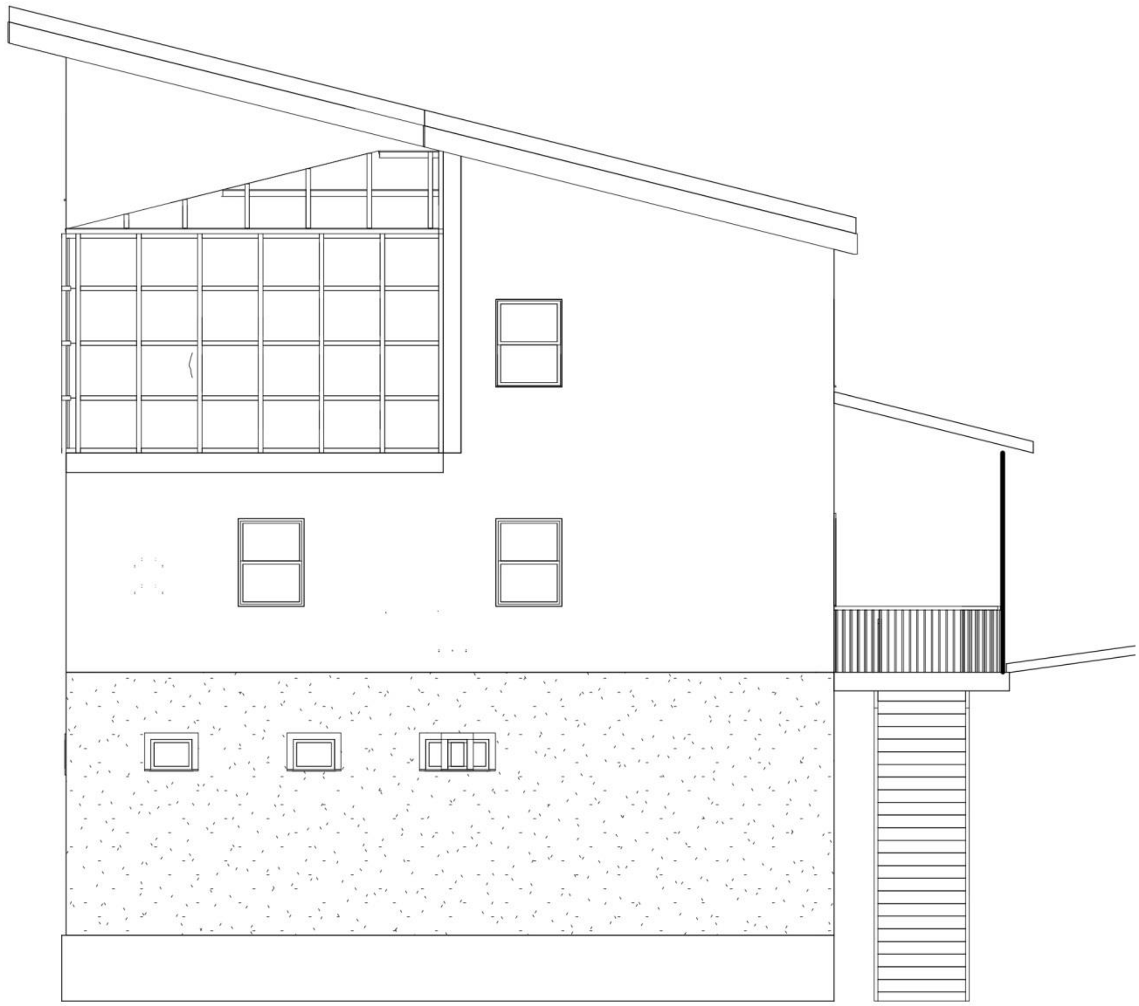

Figure 5.36 *(House Prototype 2: South Elevation)*

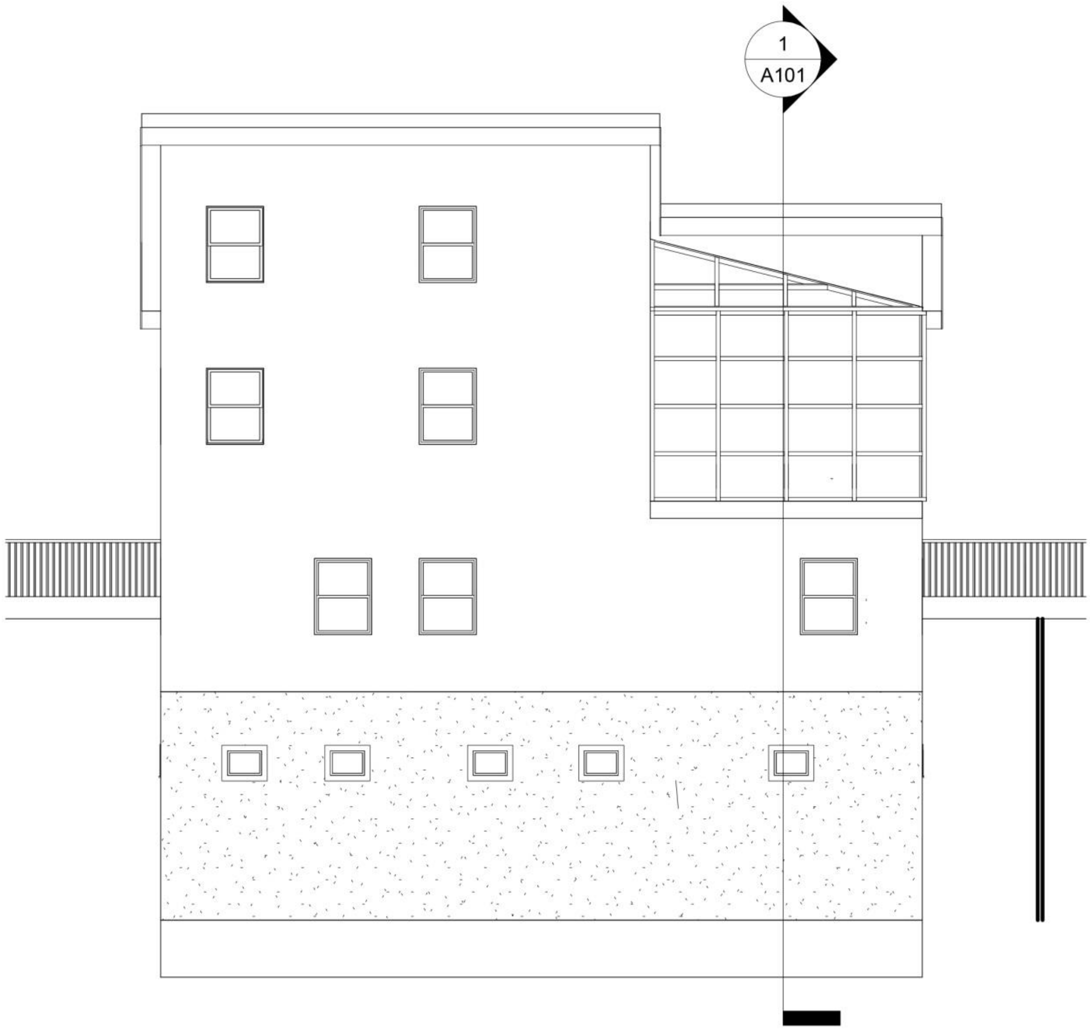

Figure 5.37 *(House Prototype 2: West Elevation)*

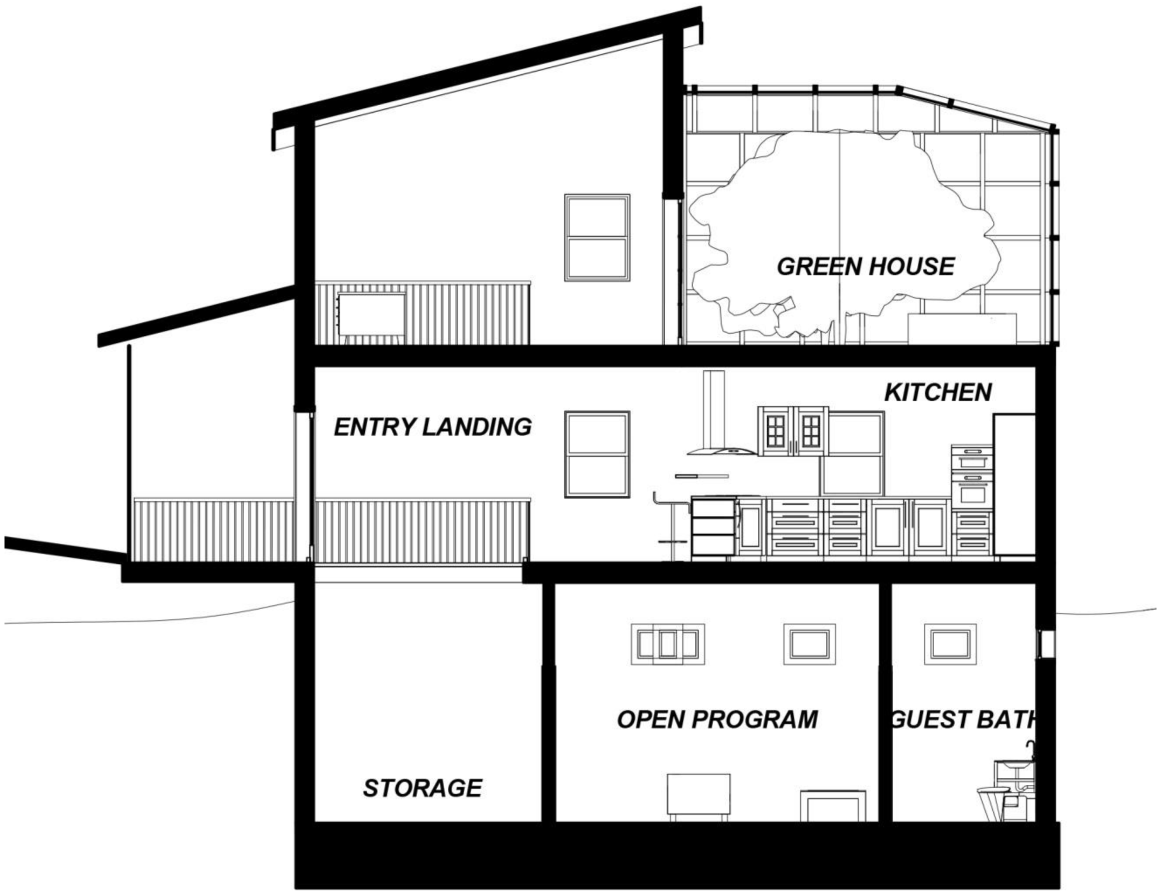

Figure 5.38 *(House Prototype 2: Section)*

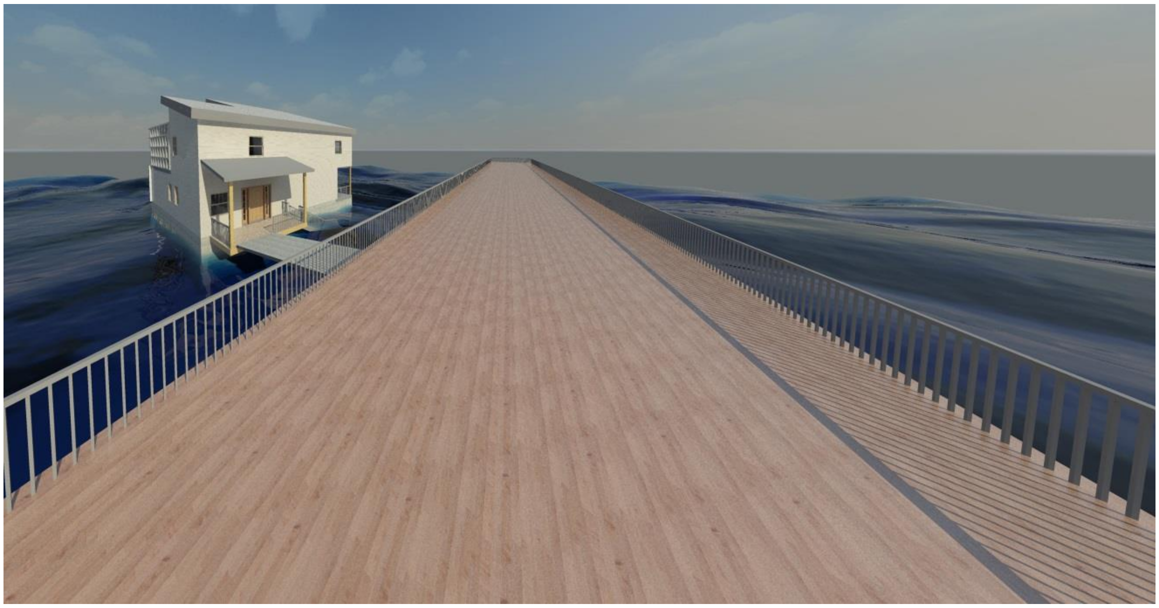

Figure 5.39 *(House Prototype 2: exterior rendering)*

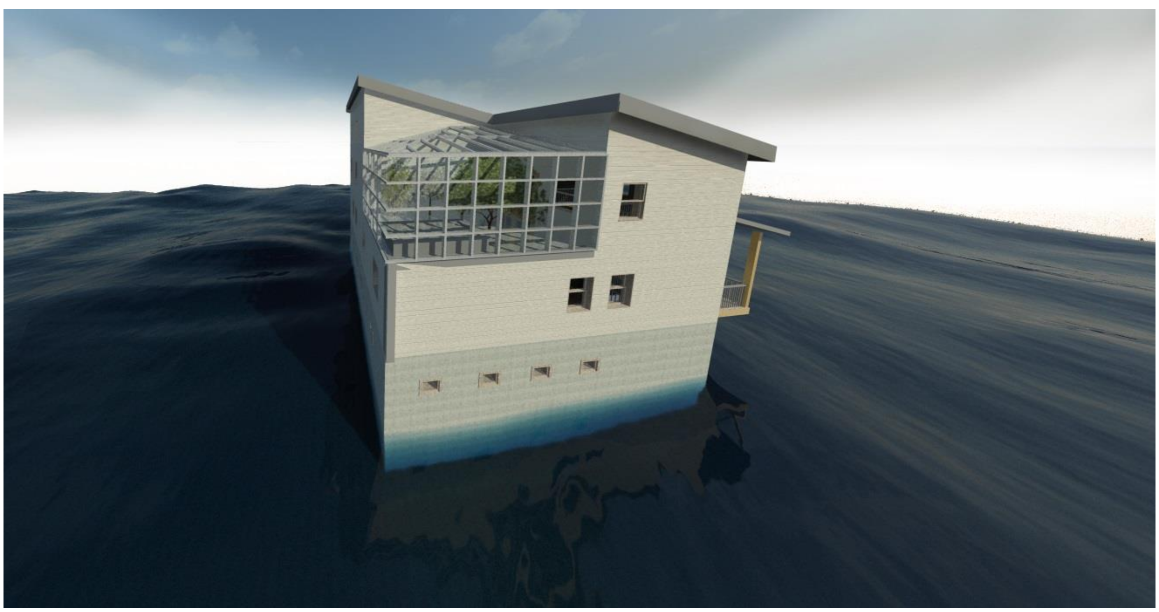

Figure 5.40 *(House Prototype 2: exterior rendering)*

HOUSE 3 AND BEYOND –

The possiblities of housing types and the variations within them are endless, despite the previously mentioned constraints. It is within these constraints that interesting ideas and programs may be developed. The renderings of a third prototype shown in Figures 5.41 and 5.42 show a home that has a lawn built into it.

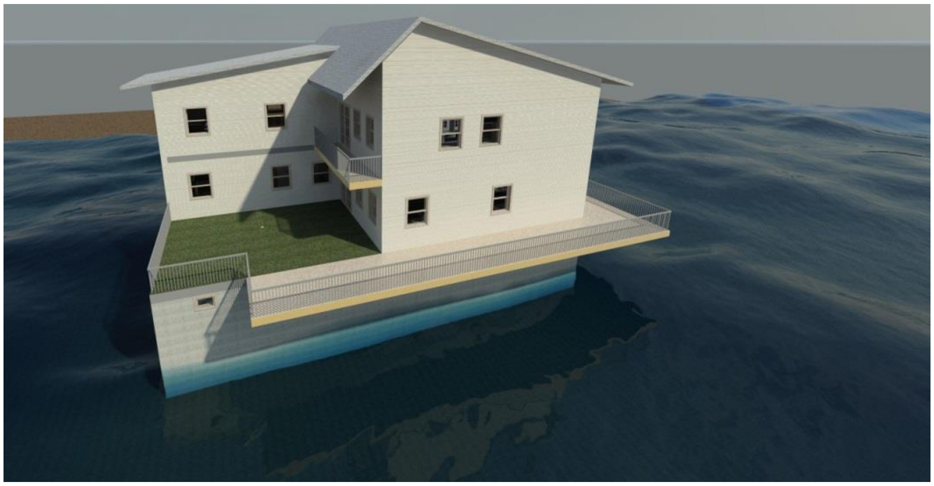

Figure 5.41 *(House Prototype 3: exterior rendering)*

Figure 5.42 *(House Prototype 3: exterior rendering)*

A VISION FOR TYBEE –

This adaptation plan for Tybee is a very comprehensive and thorough one. It is not a disjointed effort at mitigating threats as they emerge. This plan evaluates the risks of sea level rise holistically and as they apply to the island. The ecology, economy, and human habitation of Tybee are inextricably linked, so it logically follows that any adaptation plan must consider this linkage in addressing, preserving, and adapting them. Below are some renderings of a vision for Tybee Island. This vision for Tybee is one of adaptation. Rather than building up walls and structure to keep nature out, the future Tybee Island adapts and changes with the change in climate. The community grows in harmony with the rising sea, and is richer for it. A new identity is created, a burgeoning economy is sparked, and Tybee becomes an even bigger destination than it already is.

Figure 5.43a *(Transformation of Tybee_Existing: SLR +00')*

Figure 5.43b *(Transformation of Tybee_SLR +03')*

Figure 5.43c *(Transformation of Tybee_SLR +06')*

Figure 5.43d *(Transformation of Tybee_SLR +09')*

Figure 5.44 (*Vision of Tybee)*

Figure 5.45 *(Vision of Tybee)*

AUTHOR'S NOTE

This thesis was an academic exercise founded in real data and research. Though this document summarizes a year and a half of research, design, revision, and planning, I do not intend for this to be the culminating document of my interest in and desire for change in the fields of planning, urban design, and architecture in regards to climate change. I plan on refining this document and pursuing real world applications of the lessons learned during its formation.

If you, as the reader, are interested in contacting me for further material, information, questions, comments, concerns, or opportunities for collaboration I would be more than happy to make myself available. My contact information is listed below and thank you for taking the time to read.

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